MIT Technology Review

The Economy Issue

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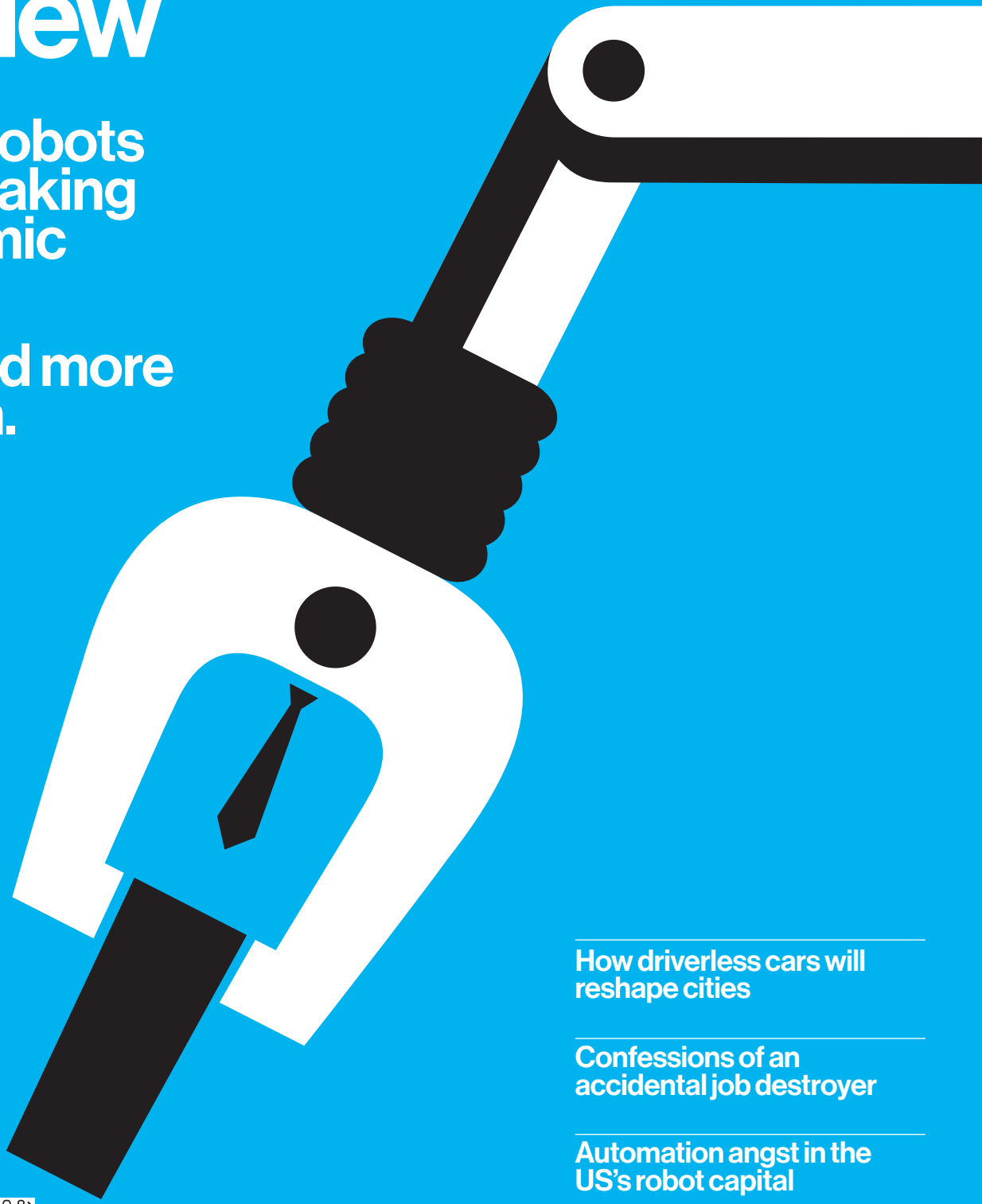
AI and robots are wreaking economic havoc.

We need more of them.



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Gideon Lichfield is editor in chief of MIT Technology Review.

Almost exactly 20 years ago, what was then called just *Technology Review* was relaunched with a fresh design and the tagline "MIT's Magazine of Innovation." The dot-com boom was nearing its peak, and hip young journals like *Wired*, *Fast Company*, and *Red Herring* were selling their readers a swaggering vision of a future in which, if you were only tech-savvy enough, you would be richer and sexier, live longer, and have cooler friends. The 99-year-old, somewhat stuffy *Technology Review* decided it could go after a wider audience and, in the words of its editor, John Benditt, "initiate a national dialogue on technology and innovation."

Since then, countless new publications have emerged to try to tap into the promise of technology. But the swagger has faltered. Online trolling, fake news, social-media echo chambers, election hacking, cybercrime, immensely powerful tech firms, privacy breaches, job automation … perhaps not since the invention of nuclear power or pesticides has it been so starkly clear that technology cuts both ways.

Melvin Kranzberg, a historian at Georgia Tech, summed up that fact in 1985 as "technology is neither good nor bad; nor is it neutral." By this he meant that a technology can have both good and bad effects, which aren't inherent to it but depend on how and where it is used. Obvious though that seems, it appears to be routinely forgotten both by those who build new technologies without planning for their potential impacts and by those who want to halt them outright.

To take Kranzberg seriously, however, is to accept an equally obvious-seeming corollary: technology is not a *force majeure* that we must either oppose or submit to, but a product of human actions and decisions. We can choose to build and use it in ways that maximize the good and minimize the harm. "You can't stop progress!"—sure. But you can direct its course.

Unfortunately, those who build technology, those who use and are affected by it, and those who create its legal, regulatory, and financial frameworks—its makers, users, and framers, to coin a shorthand—often aren't choosing well. Makers are usually too focused on financial success; users cannot see how their lives are gradually but fundamentally changing; and framers rarely understand the inventions for which they are writing laws, rules, or checks. This leads to ill-informed decisions by all three groups.

That's why we're launching this redesigned *MIT Technology Review* with a new mission statement: "to bring about better informed and more conscious decisions about technology through authoritative, influential, and trustworthy journalism." We think it's no longer enough for tech journalism to merely explain technology and its ramifications. Rather, it should explicitly strive to make technology more of a force for good, by helping its makers, users, and framers reach better decisions.

We'll do that in a number of ways, including writing more about tech ethics and policy. But we're also changing the notion of what a printed magazine is for.

For years the web was just a place for magazines and newspapers to republish their printed stories. Today, in the digital-first era, it's the other way around; a print edition is typically a "best of" collection of stories that first appeared online (minus the interactive bits). But our approach assumes that since people use print and digital media differently, they should serve different purposes.

Online, we'll continue to cover a wide swath of emerging technologies, in stories ranging from short news items to in-depth reports of the kind the magazine has always published. In print, though, each issue is now more like a book, examining a single technology or theme from a wide range of angles in an attempt to get at some of the deeper questions about how it affects our world and how decisions about it get made. The issue you're reading now is all about the economy—what the confluence of AI, big data, and powerful tech firms means for the future of how we work and where prosperity will come from. (Flip it over, and you'll also find our annual list of 35 young innovators to watch.)

I've already heard from several readers who dislike the shift to themed issues, regardless of what we do online. I'm convinced, though, that the move will help us play a bigger part in what's becoming a crucial global conversation about how to ensure that technology makes life better for everyone, not just those lucky enough to be the winners.

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The economy issue

How we got here

Where we are now

What comes next

PLUS: Flip to the back of this issue for our annual list of 35 innovators under 35

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How we got here

1

Making

AI

into

jobs

By **David Rotman**

Artificial intelligence is offering an amazing opportunity to increase prosperity, but whether or not we will seize it is our choice.

Mill 19 at Hazelwood Green in Pittsburgh is a former coke works being redeveloped.

Photograph by Rob Larson

Can AI, advanced robotics, self-driving cars, and other recent breakthroughs spread prosperity to the population at large?

The vast vacant lot along the Monongahela River has been a scar from Pittsburgh's industrial past for decades. It was once the site of the Jones and Laughlin steelworks, one of the largest such facilities in the city back when steel was the dominant industry there. Most of the massive structures are long gone, leaving behind empty fields pocked with occasional remnants of steelmaking and a few odd buildings. It all stares down the river at downtown Pittsburgh.

Next to the sprawling site is one of Pittsburgh's poorer neighborhoods, Hazelwood, where a house can go for less than $50,000. As with many of the towns that stretch south along the river toward West Virginia, like McKeesport and Duquesne, the economic reasons for its existence—steel and coal—are a fading memory.

These days the old steel site, called Hazelwood Green by its developers, is coming back to life. At one edge, fenced off from prying eyes, is a test area for Uber's self-driving cars. A new road, still closed to the public, traverses the 178 acres of the site, complete with parking signs, fire hydrants, a paved bike path, and a sidewalk. It doesn't take much imagination to picture it bustling with visitors to the planned park along the riverfront.

The gem of the redevelopment effort is Mill 19, the former coke works. A structure more than a quarter-mile long, sitting amid the empty fields, it has been stripped clean to a three-story metal skeleton. Crews of workers are clearing away remaining debris and preparing the building for its reincarnation. By next spring, if all goes according to plan, its first occupant will move in: the Advanced Robotics for Manufacturing Institute.

The symbolism of robots moving into a former steelworks is lost on few people in the city. Pittsburgh is reinventing itself, using the advances in automation, robots, and artificial intelligence coming out of its schools—particularly Carnegie Mellon University (CMU)—to try to create a high-tech economy. Lawrenceville, five miles from Hazelwood, has become a center for US development of self-driving cars. Uber Advanced Technologies occupies a handful of industrial buildings; self-driving startups Argo AI and Aurora Innovation are nearby. Even Caterpillar has set up shop, working on autonomous backhoes and other heavy machines that could one day operate themselves.

This has drawn billions of dollars from Silicon Valley and elsewhere, a welcome development in a city whose economy has been moribund for decades. And the effects are visible. Self-driving cars out for a test ride are a common sight, as are lines outside the trendy restaurants in what civic boosters call "Robotics Row." While many longtime residents complain of skyrocketing home prices near the tech firms' headquarters and test facilities, they'll also tell you these are the best days the city has seen in their lifetimes.

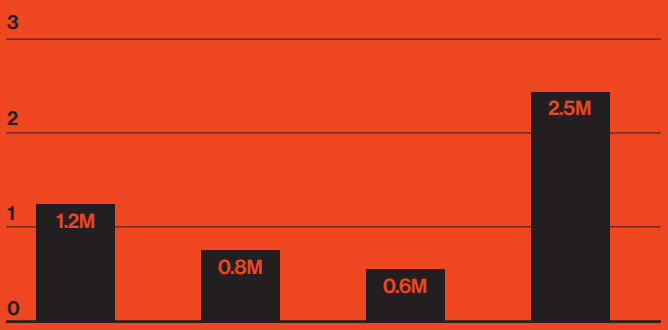
But despite all this activity, Pittsburgh's economy is struggling by many measures. Though the city's population is no longer hemorrhaging away—between 1970 and 1980 it fell by roughly a fifth—it isn't growing, either, and is aging quickly. During the last half-decade, almost 70,000 people aged 35 to 54 have left the region. And not far from the city and its elite universities, in areas where the main hope for prosperity lies in coal and natural gas from fracking rather than self-driving cars, well-paying jobs are scarce and towns are being devastated by opioid addiction.

Automation is changing work

Gauging the net gain or loss of jobs due to robotics and AI is a tricky business. But it's clear that the kinds of jobs in demand are changing as the need for manual labor declines and that for digital and human skills soars.

What will be the impact of jobs lost to automation? It could be huge.

Average annual workers displaced, scaled to the size of the 2016 total US labor force (in millions)



Agriculture to industry 1900–1940	Manufacturing 1970–1990	Construction 2007–2010	The Great Transformation 2020 onward
Nearly 40% of labor force displaced	Nearly 13% of labor force displaced	Nearly 0.5% of labor force displaced	20%–25% of labor force displaced

BAIN & CO.: LABOR 2030

~50% of current work activities in the US are technically automatable by adapting existing technologies

6 of 10 current occupations have more than 30% of activities that are technically automatable

MCKINSEY GLOBAL INSTITUTE

Most Americans favor limits on replacing jobs through automation.

A 2017 Pew Research Center poll found that a majority of adults thought businesses should be limited in their use of machines that replace humans.

41% Businesses are justified in replacing human workers if machines can do a better job at a lower cost

58% Should be limits on number of jobs businesses can replace with machines, even if they are better and cheaper than humans

PEW RESEARCH CENTER

The demand for various skills is rapidly changing, with winners and losers.

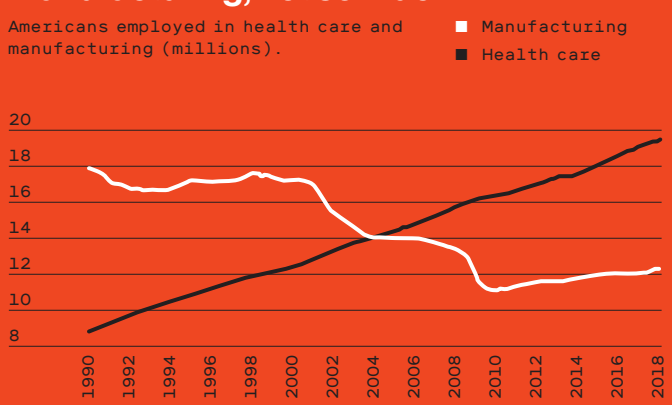
Automation and AI will mean less need for physical labor and much more demand for high-tech and social skills.

	United States		Western Europe	
Skills	Hours worked in 2016 (billions)	Change in hours worked by 2030 (%)	Hours worked in 2016 (billions)	Change in hours worked by 2030 (%)
Physical and manual	90	-11	113	-16
Basic cognitive	53	-14	62	-17
Higher cognitive	62	+09	78	+07
Social and emotional	52	+26	67	+22
Technological	31	+60	90	+52

MCKINSEY

Employment in health care is soaring. In manufacturing, not so much.

Americans employed in health care and manufacturing (millions).



ABOVE: US BUREAU OF LABOR STATISTICS; BELOW: ACEMOGLU/RESTREPO 2017

Each industrial robot in manufacturing replaces 6 workers.

+1 robot = -6 jobs

Reinventing Pittsburgh

Mayor William Peduto, a Democrat elected in 2013, has been at the center of the city's high-tech reincarnation. We asked how it's going.

On the best use of new technologies: "What good is it if we develop autonomous vehicles that only create more congestion on our streets? That deny people mobility unless they have a smartphone or credit card? Are we really creating a better society? And if we aren't, why are we investing in it?"

On the region around Pittsburgh: "Our neighbors throughout the Rust Belt are still going through a recession. They're still not seeing any part of the new economy directly connecting to them. One of the reasons that President Trump did so well is that he offered them a false narrative of bringing back the mills and bringing back the mines. As Democrats we offered them no hope. Saying to someone who has generations' worth of making and building things that you're going to be retrained as a coder is an insult."

On new jobs: "We don't want to create a society based on PhDs; we want to include GEDs."

On the city's progress: "We're right at the beginning. We're at the beginning of the next phase of Pittsburgh. Those who lived through the '80s and '90s will tell you these are the best days. We went through those decades exporting people like we used to export steel. It has been a slow death of a former economy, but from it has come a new, more diverse economy. So it's at the beginning phases."

On lessons for executives in Silicon Valley: "What I reminded them is that we were you before Silicon Valley existed. We were where the great wealth was and where all the jobs were being created 100 years ago. And we created air that was dangerous to breathe, water that was poisonous to drink, and the greatest disparity between the haves and the have-nots in American history. Learn from us."

On hearing from Amazon: "Nah. They made it very clear. They said they will make a decision in 2018, but they never gave us a specific timeline."

This makes Pittsburgh not only a microcosm of the US industrial heartland but a test case for the question facing every city and country with access to new digital technologies: Can AI, advanced robotics, self-driving cars, and other recent breakthroughs spread prosperity to the population at large, or will they just concentrate the wealth among entrepreneurs, investors, and some highly skilled tech workers?

To prosper, says Scott Andes at the National League of Cities, Pittsburgh "can't just be a producer of brilliant talent and ideas that then don't turn into job generation." He adds, "Pittsburgh is a great case study for the 21st-century economy, because it is beginning to leverage research strengths into economic value."

Changing jobs

There is no sillier—or more disingenuous—debate in the tech community than the one over whether robots and AI will destroy jobs or, conversely, create a great abundance of new ones. In fact, the outcome depends on various economic factors. And how it will play out as the pace of AI intensifies, no one knows.

Automation and robots have certainly wiped out many jobs over the last few decades, especially in manufacturing. In one of the first attempts to quantify the impact of industrial robots, research by Daron Acemoglu at MIT and his colleagues, based on data from 1990 to 2007, found that for every robot on the factory floor, some six jobs are lost. That means as many as 670,000 jobs for the years that they looked at, and as many as 1.5 million jobs at 2016 levels of robot usage in the US.

The McKinsey Global Institute estimates that about 50 percent of tasks done in our economy could be automated. But such statistics are often misinterpreted. The 50 percent merely describes the "technical feasibility" of what can be automated with existing and emerging technologies, says James Manyika, the institute's chairman. The number of actual jobs lost will depend on the costs and benefits of replacing people with machines.

Even more uncertain is how many new jobs will be created. Many technologists, especially roboticists, assert that advances will lead to a wealth of new kinds of work. So far, though, that hasn't happened, and few of the breakthroughs have reached the largest sectors of the US economy, such as health care.

Perhaps we just need to be patient; technology advances have always increased incomes, which then increased demand for goods and services, which then led to more jobs. But Laura Tyson, a top economic advisor to President Bill Clinton and a professor at the University of California, Berkeley, asks the question that is on everyone's mind: What if, this time around, the goods and services that people want just don't require much human labor to produce? "This is the first time that technology, we think, could on net reduce the demand for human workers," she says.

"The naïve view among macroeconomists for several decades has been that technology will always create jobs," says Acemoglu. "The alarmists' is that this time is different and it will destroy jobs. The truth is it's capable of doing both." Though in the past the economic benefits from new technologies have always been enough to create more jobs than were lost, he says, "lately, for a variety of reasons, there has been a much more job-destroying face to technology."

Part of what he's describing is the so-called productivity paradox: while big data, automation, and AI should in theory be making businesses more productive, boosting the economy and creating more jobs to offset the ones being lost, this hasn't happened. Some economists think it's just a matter of time—though it could take many years (see "The productivity paradox," opposite).

But the debate about how many jobs are gained or lost obscures a

much more important point. The location of jobs and the kind of work they involve are changing, and that's what's causing real pain to people and to local economies.

In the US, demand for low-paying work in places like warehouses and restaurants is growing; so is demand for well-paying work in occupations requiring lots of technical skills, such as programming. At the same time, many traditionally middle-class jobs in areas like manufacturing and data processing are shriveling. These trends have contributed to record levels of income inequality. "There is not a lot of disagreement that technology is changing the skills and occupations in demand," says Tyson. "And that will continue to increase income inequality."

This movie has, of course, played out before. In 1900, about 40 percent of US workers were on farms; today fewer than 2 percent are. In 1950, about 24 percent of the jobs were in manufacturing; today around 9 percent are. Similar shifts are occurring in other developed countries. But today's changes are happening faster and more broadly than before, leaving little time for people to adapt.

Many are simply giving up on finding a decent job. Labor-force participation—basically, the proportion of people working or seeking work—is showing a troubling drop, especially for men aged 25 to 54. Melissa Kearney and Katharine Abraham, economists at the University of Maryland, have looked at why. They think there may be several causes, but they say robots and automation are a critical one. Many people without a college degree simply think the prospects of finding a well-paying job are too slim to make it worth looking.

Princeton economist Anne Case and her coauthor Angus Deaton have identified what's likely a related trend. They found that mortality is rising among middle-aged white people in the US with a high school diploma or less. The culprits: high rates of suicide, drug addiction, and alcoholism, which Case and Deaton call "diseases

The productivity paradox

To become wealthier, a country needs strong growth in productivity—the output of goods or services from given inputs of labor and capital. For most people, in theory at least, higher productivity means the expectation of rising wages and abundant job opportunities.

Productivity growth in most of the world's rich countries has been dismal since around 2004. Especially vexing is the sluggish pace of what economists call total factor productivity—the part that accounts for the contributions of innovation and technology. In a time of Facebook, smartphones, self-driving cars, and computers that can beat a person at just about any board game, how can the key economic measure of technological progress be so pathetic? Economists have tagged this the "productivity paradox."

Some argue that it's because today's technologies are not nearly as impressive as we think. The leading proponent of that view, Northwestern University economist Robert Gordon, contends that compared with breakthroughs like indoor plumbing and the electric motor, today's advances are small and of limited economic benefit. Others think productivity is in fact increasing but we simply don't know how to measure things like the value delivered by Google and Facebook, particularly when many of the benefits are "free."

Both views probably misconstrue what is actually going on. It's likely that many new technologies are used to simply replace workers and not to create new tasks and occupations. What's more, the technologies that could have the most impact are not widely used. Driverless vehicles, for instance, are still not on most roads. Robots are rather dumb and remain rare outside manufacturing. And AI is mysterious for most companies.

We've seen this before. In 1987 MIT economist Robert Solow, who won that year's Nobel Prize for defining the role of innovation in economic growth, quipped to the *New York Times* that "you can see the computer age everywhere but in the productivity statistics." But within a few years that had changed as productivity climbed throughout the mid and late 1990s.

What's happening now may be a "replay of the late '80s," says Erik Brynjolfsson, another MIT economist. Breakthroughs in machine learning and image recognition are "eye-popping"; the delay in implementing them only reflects how much change that will entail. "It means swapping in AI and rethinking your business, and it might mean whole new business models," he says.

In this view, AI is what economic historians consider a "general-purpose technology." These are inventions like the steam engine, electricity, and the internal-combustion engine. Eventually they transformed how we lived and worked. But businesses had to be reinvented, and other complementary technologies had to be created to exploit the breakthroughs. That took decades.

Illustrating the potential of AI as a general-purpose technology, Scott Stern of MIT's Sloan School of Management describes it as a "method for a new method of invention." An AI algorithm can comb through vast amounts of data, finding hidden patterns and predicting possibilities for, say, a better drug or a material for more efficient solar cells. It has, he says, "the potential to transform how we do innovation."

But he also warns against expecting such a change to show up in macroeconomic measurements anytime soon. "If I tell you we're having an innovation explosion, check back with me in 2050 and I'll show you the impacts," he says. General-purpose technologies, he adds, "take a lifetime to reorganize around."

Even as these technologies appear, huge gains in productivity aren't guaranteed, says John Van Reenen, a British economist at Sloan. Europe, he says, missed out on the dramatic 1990s productivity boost from the IT revolution, largely because European companies, unlike US-based ones, lacked the flexibility to adapt.

Economic pain

Laura Tyson, a former top economic advisor to President Clinton, explains how technology is increasing inequality.

On inequality: "I think there is a consensus based on what we know from the past 30 years about what will happen as a result of ongoing technological change; it will be labor-replacing and skill-biased. And this kind of technological change will lead to the continued erosion of the labor share of national income, growing wage inequality, and growing income inequality."

On what's new: "The pace of automation is increasing, and it is spreading across more skills, tasks, occupations, and sectors. So it is not just the pace but also the breadth of change."

On not leaving people behind: "If workers in their late 40s or mid 50s are replace by automation, will they actually be able to acquire the skills required for new jobs, and will they actually be hired if they acquire those skills? We have to invest a lot in skills and education and mobility, and—even though that sounds hard—it's harder than you think."

On understanding what's happening: "It's almost simple Econ 101. Technology will displace more and more humans and more and more tasks currently done by humans. That will reduce the demand for labor, which in turn will reduce the returns to labor. My concern is what this does to wages. If a significant share of human workers have the value of their skills undermined by automation, it means lower wages. It's that simple."

On productivity: "I continue to believe productivity gains will be substantial. The question is, how will they be shared?"

On tech unemployment: "I'm of the view that we're not headed for sustained technological unemployment. In a market economy, wages adjust over time and people will find jobs. The question is not the number of jobs but the quality of jobs. Will they provide livelihood levels and opportunities comparable to livelihoods and opportunities of the jobs lost through automation? This worries me."

of despair" because they don't seem related to poverty per se, but rather to disappointment; in a reversal of expectations, people are realizing they won't be better off than their parents.

Automation might be partly to blame for these social problems. But if economists like Acemoglu are right, the key to creating more good jobs is not fewer of these advances but better versions of them that are deployed faster throughout the economy.

Pittsburgh reborn

That, in essence, is what Pittsburgh's attempt at reinventing itself is about. So far the results are mixed. "The transformation of the city by new, young people working in AI and robotics has been spectacular," says Andrew Moore, dean of computer science at CMU. "But it has been more of an approach of gentrification rather than an inclusion of the community."

That criticism resonates in a place that prides itself as a working-class city with strong unions and a rich history of progressive politics. Mayor William Peduto helped attract Uber to the city, but he has since soured on the San Francisco–based company. "The Silicon Valley model doesn't [put] people in the equation. It is based on what return will be derived for VCs," he said in a recent interview at city hall with *MIT Technology Review*. "In places like Detroit and Pittsburgh, when we look at the future of work, we want to know what the future of the worker is."

According to a recent poll, more than half of Pittsburgh residents would strongly support Amazon's building its second headquarters there. That's far more than in many cities on Amazon's shortlist—in Austin and Boston only around a third of the population would welcome the move. It's hardly surprising: Amazon is pledging 50,000 jobs and $5 billion in investment, which would be transformative for Pittsburgh. It's rumored that the city is tempting the company with the site along the Monongahela River that includes Mill 19.

But if Amazon picks Pittsburgh, that's likely to exacerbate the anxiety over how to match residents with new high-tech jobs. "There is nowhere near enough people in the city and the region with the technical skills," says CMU's Moore. "We're great in terms of the rare genius leaders, but [Pittsburgh] really needs to skill up the local population to take part in this."

The challenge facing the city and the rest of the country, though, is not only to include more people in the high-tech workforce but to expand the supply of those well-paying jobs. Advanced robotics can modernize the factories in a city like Pittsburgh and help make manufacturing more competitive. But the factory jobs lost through the years aren't coming back. As a country, we're struggling to imagine how to build an economy with plenty of good jobs around AI and automation.

A person standing on the flat roof of a building in the Lawrenceville neighborhood can get a glimpse of the future. On the first floor is a large garage housing several of Aurora's self-driving cars. Off in some weedy fields is a Caterpillar backhoe belonging to the company's research outpost for autonomous machines. Beyond that is a fenced-in testing area next to yet another former steel facility—this one housing Carnegie Robotics, which is working on a bomb-clearing robot for the Army. In the background is the National Robotics Center, another imposing building and home—until it moves into Mill 19—of the Advanced Robotics for Manufacturing Institute.

It's an impressive scene highlighting signs, if you know where to look, of some of the world's leading research into robotics and automation. But it is also almost deadly quiet. There are a few cars in the parking lots—those of the engineers and programmers involved in the various robotic ventures, and probably some visitors. Beyond that, there are no signs of workers anywhere.

David Rotman is the editor of MIT Technology Review.

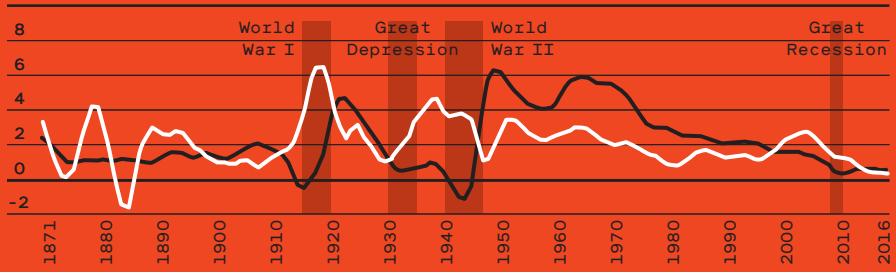
Inequality is up as growth slows

Despite advances in AI and robotics, productivity is sluggish, and fewer people are enjoying the benefits. To boost growth, especially as workforce growth slows, we will need more AI, and we'll need to learn how to deploy it better.

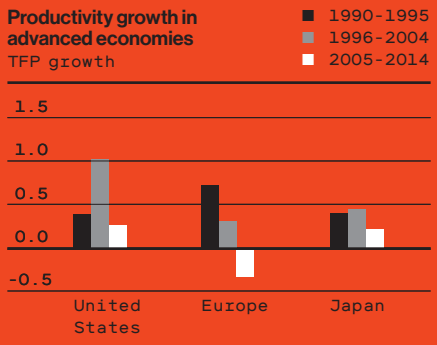
Productivity is at near historic lows in the US, after a bump during the '90s.

Productivity figures are worrisome—particularly total factor productivity (TFP), which is attributed to innovation.

Labor productivity growth is slowing
% year over year



Productivity growth in advanced economies
TFP growth

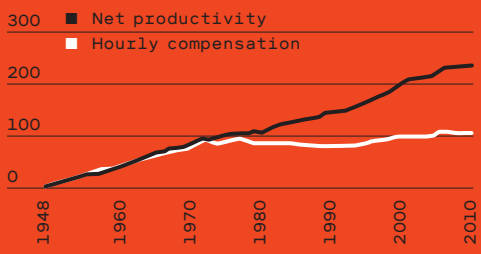


LEFT: MCKINSEY GLOBAL INSTITUTE: SOLVING THE PRODUCTIVITY PUZZLE; BROOKINGS INSTITUTION

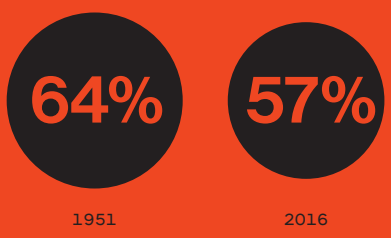
Even as the economy grows, many workers aren't sharing in the prosperity.

The share of the US's income going to workers is declining, as more goes to the owners of capital. The trend contributes to wage stagnation and income inequality.

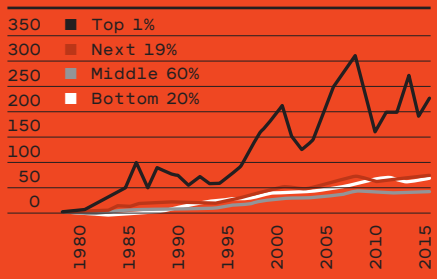
US productivity is growing, but wages aren't keeping up
% indexed to 1948



US labor share of output



Income gains at the top are rising fastest
% change in income, US households

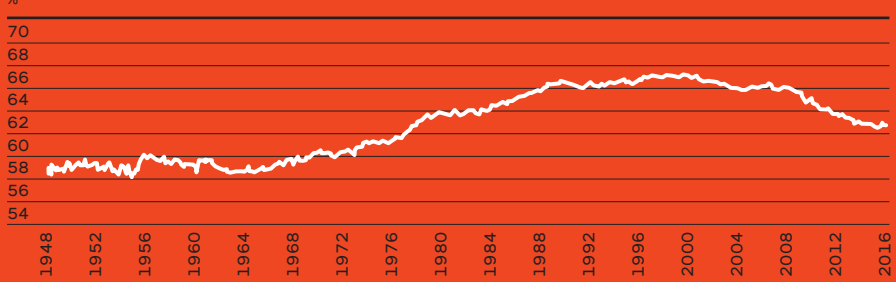


LEFT/MIDDLE: BAIN & CO; LABOR 2030; CENTER FOR BUDGET AND PRIORITIES

A troubling number of people are giving up on joining the workforce.

A nation's GDP depends on both the size of its workforce and its productivity. An aging workforce means that even with robust productivity, GDP will plummet in coming decades.

US labor force participation rate for people 16 and older, seasonally adjusted, 1948–2016
%



US employment growth is slowing, and that will drag down the overall economy.

If productivity continues growing at the rate of the past 50 years, the result will be:

40% decrease
in GDP growth over the next 50 years

To compensate fully for slower employment growth, the need will be:

80% increase
in productivity over the next 50 years

LEFT: BUREAU OF LABOR STATISTICS; RIGHT: MCKINSEY

The conflict between labor and capital has shifted in capital's favor. But there are some ways labor could fight back.

By
Ryan Avent

A digital capitalism Marx might enjoy

Private ownership of capital is the defining feature of most of the world's economies. The conflicts between the owners of capital and the laborers who operate it for them defined two centuries of history. Not for nothing did Karl Marx title his indictment of industrial economies, simply, *Capital*. Yet the nature of capital changes with time and technology. The world may soon face a new era of conflict between labor and capital, based on a relationship between the two far different from that which animated Marx.

For most of industrial history, capital meant tangible things like looms and furnaces and other machines that you could see and smell and fall into if you were insufficiently cautious. Capitalists spent heavily to outfit their factories, and they put the maximization of these factories' output above all else. But they also depended on a growing workforce to operate the machines. Capital and labor each sought to prevent the other side from gaining the power to dictate the terms of the relationship—and the distribution of profits generated by it.

Today's corporate giants rely on different sorts of capital entirely, with very different demands. In their recent book, *Capitalism Without Capital*, Jonathan Haskel and Stian Westlake describe a 2006 analysis of Microsoft. The company's market valuation at the time was about $250 billion. But its book value was only $70 billion, largely cash and financial instruments, while a mere $3 billion or so could be ascribed to what is usually thought of as capital: plants and equipment. Almost all of Microsoft's worth was in intangible assets like its intellectual property and brands. Intangibility is most pronounced in tech firms, but it's important across the economy. A recent analysis found that less than 20 percent of the market value of S&P 500 firms was due to the tangible assets on their balance sheets—a reversal of the ratio that prevailed in the 1970s.

Today most capital, in value terms at least, lives in neurons and silicon rather than on factory floors. The computerization of everything from toothbrushes to pickup trucks means that ever more of a good's value derives from the software that operates it. The know-how needed to design and build such products (and to manage the complex supply chains that actually produce them) is yet another component of intangible capital. The growing power and appeal of AI stretches the definition of capital still further. Machine-learning programs are an odd form of quasi-labor, trained on data generated by people to do tasks previously done by people. Yet they are owned and controlled by firms in the same way a truck or computer would be.

This evolution fundamentally changes the relationship between labor and capital. While the world of industrial capitalism was shaped by the conflict between the two, there was nonetheless a certain balance of power, since they also needed each other to unlock the riches made possible by technological change. Digital capitalism is different.

On the one hand, as machines grow increasingly autonomous, capital will need fewer workers. In the industrial era, machinery was a substitute for some workers but a complement to many others, such as the tens of millions of relatively low-skilled workers needed to operate factory equipment. Ever more capable AI, in contrast, is very nearly a pure substitute for labor. As it spreads across the economy, labor will lose both leverage within the workplace and the moral claim to a share of the economy's profits that working provides.

Yet on the other hand, labor is not really becoming less essential, at least not yet. To a great extent, intangible capital is people. Within the elite firms developing and deploying the technologies that are changing

Capital is learning from labor in order to mimic labor and eventually replace it.

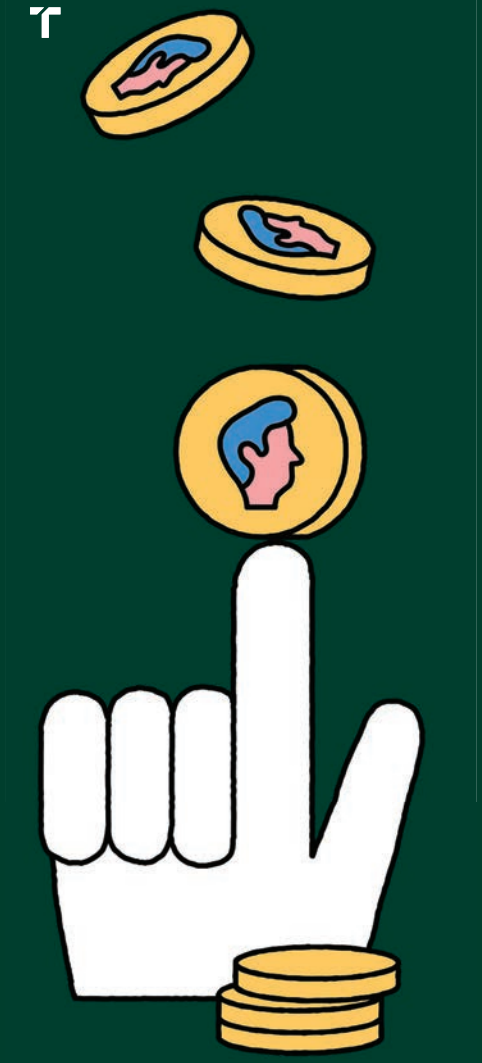


Illustration by Tim Lahan

the economy, the most valuable corporate capital is the culture—the procedures and norms that shape interactions between highly skilled workers, turning their individual expertise into profitable new ways of doing things. This culture is not like computers or robots; it lives in the heads of workers, who modify it all the time and pass it along to new colleagues.

All the same, labor is being weakened. Even those workers who remain indispensable struggle to capture the returns on the intangible capital to which they contribute. An effective firm culture is a competitive advantage, which cannot easily be replicated by upstart competitors and which workers cannot credibly threaten to take with them if they go. Within the world's most valuable companies, asymmetric bargaining power allows the returns on this cultural capital to flow mostly to shareholders.

Across the rest of the economy, meanwhile, technology squeezes workers' bargaining power by giving firms ever more scope to automate or outsource jobs when employees get too fussy or demand pay raises. People whose personal data makes up much of tech firms' value cannot claim a share of that value either.

This problem will grow more severe over time. The AIs that promise to displace millions of workers are just clever aggregations of countless human actions and communications. Across most of the workforce, capital is learning from labor in order to mimic labor and, eventually, replace labor—all without compensating labor for its enabling role in this process.

Having lost their leverage in the workplace, workers might instead use the ballot box to secure more of the capitalists' wealth, whether through tax reforms that give fewer breaks to owners and shareholders, and make it cheaper to invest in people, or in the more radical form of a basic income or government-provided make-work. But while such strategies might save people from poverty, it would not recognize workers' earned right to the economy's bounty—only the state's responsibility to provide for those who cannot provide for themselves.

In a new book, *Radical Markets*, Eric Posner and Glen Weyl describe a very different way to give people control of, and a right to the value of, their contribution to capital. The proposal: treat the data we generate while talking to Alexa or liking things on Facebook as the output of a job of sorts, for which the big tech companies ought to pay us a wage. In other words, treat the data these firms amass as labor, not capital.

In such a world we might, on liking a friend's photo, be asked by the social network of our choice to provide some contextual data in exchange for payment. Getting paid for our data, Posner and Weyl suggest, could mitigate the harm of mass unemployment, recognize what people contribute to production even if they don't work at a company, and perhaps give the economy a productivity boost too, since companies would find it easier to obtain high-quality data. Perhaps, they say, the data generators of the world could unite and form a data union, the better to negotiate with big tech companies on fair terms.

But this might all prove too clunky or difficult to organize. Do we really want to spend our days providing metadata to big companies in exchange for micropayments? And would those payments be enough?

Instead, society might settle on a different, collective approach. Data itself could be considered a public resource. The companies that gather data might be required to provide open access to anonymized versions of it (perhaps after the expiration of a short "data patent," which would reward the company that took the trouble to collect it with a brief period of exclusive use). In exchange for the right to access the data, firms could pay the government an annual royalty, which it might distribute across the population.

Or the government might begin taking ownership in firms itself. Giant sovereign wealth funds might buy shares on behalf of the data-generating public. Dividend payments would enrich the fund, which could in turn pay dividends to the public: the just reward for their contribution to production.

Of course, there is no reason governments can't do this right now; indeed, some essentially do. Norway, for instance, operates a sovereign wealth fund worth more than $1 trillion, which owns substantial stakes in many Norwegian companies; its returns help fund an extraordinarily generous welfare state. But the case for such a radical approach grows as information accounts for more of the indispensable capital in the economy. A giant piece of mechanical equipment can be used by only one firm at a time, and for only so long before it deteriorates. We have private property rights and free-market competition so that such equipment can find its way to its best use. But the information in our data can be replicated and reused endlessly. The best way to make sure it finds its best use is to allow anyone to access it, under appropriate conditions and in return for fair compensation to society. With new capital comes a new capitalism—perhaps one, finally, that Marx could warm to.

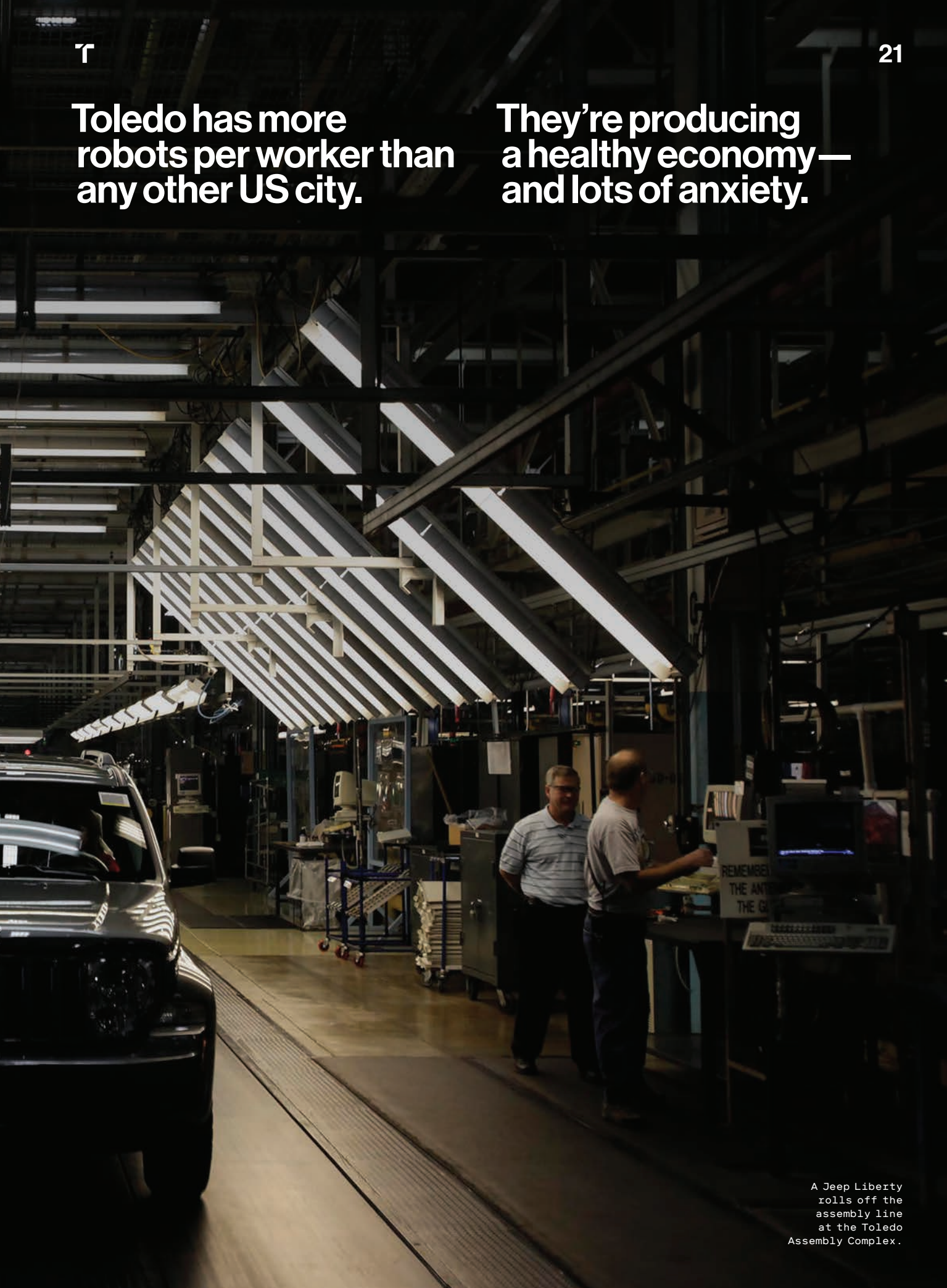
Ryan Avent is a senior editor at The Economist and the author of The Wealth of Humans: Work, Power, and Status in the Twenty-First Century.

The politics of angst in Robot City, USA

By Brian Alexander

Toledo has more robots per worker than any other US city.

They're producing a healthy economy—and lots of anxiety.



A Jeep Liberty rolls off the assembly line at the Toledo Assembly Complex.

Ronald Shrewsbery II used to be the Robot Doctor. Now he's known by the more bureaucratic-sounding title "WCM (World Class Manufacturing) Electrical Technical Specialist," but he still doctors the robots. There are a thousand of these machines inside Ohio's Toledo Assembly Complex, a 312-acre manufacturing leviathan dedicated to producing Jeeps. Huddles of one-armed robots hover over metal pieces, putting the parts together on their own. In the paint shop, robots spray coats of paint on Wrangler bodies.

The Toledo Assembly Complex is one of the most heavily automated car factories in the United States. It can extrude 500 cars in a shift, far more than the Cove, the old Jeep plant that was shut down in 2006. And the machines make the work easier. There used to be a lot more lifting, more pushing. Painters wore head-covering masks with air hoses, like old-time deep-sea divers. Welders in the body shop wrestled hanging guns. So you'd get people "with [bad] backs, arms, carpal tunnel, rotator cuffs," Shrewsbery says. "It tore you up physically." The new factory is as clean as an operating room in some spots, nothing like the darker, dirtier Cove. The cars rolling off the line are better, too.

Shrewsbery himself started in 1984 as a grunt-level assembly-line worker at the Cove. Then he bid on an opening to learn the electrician's trade, and mastered it. His story is the fulfillment of a techno-optimist's dream: automation gave him a chance to learn a new skill and earn a much better wage, just as it made the plant he works in more efficient, safer, and cleaner.

But even though the economy in Toledo is better than it has been in years, thanks in no small part to decisions by local authorities and industries to aggressively embrace new technologies, the changes are also creating an uncertain and worrisome future for many people. And they are expressing their worries at the ballot box.

Donald Trump's campaign slogan "Make America great again" resonated with many in this part of the country. The heavily industrialized counties along Ohio's western Lake Erie shore voted for Barack Obama twice. In 2016, most voted for Trump, flipping the state from the Democratic candidate to the Republican. Lucas County, where Toledo sits, did pick Hillary Clinton, but by much less than the 2:1 margins Obama had enjoyed.

In a recent paper, Oxford University researchers concluded that "Michigan, Wisconsin, and Pennsylvania would have swung in favor of Hillary Clinton if robot adoption had been 2 percent lower over the investigated period, leaving the Democrats with a majority in the Electoral College." According to a 2017 study by the Brookings Institution, the Toledo metropolitan area is the most roboticized in the United States, with nine robots per 1,000 workers. There were 702 robots there in 2010. By 2015, there were 2,374. There are more now. In March, another study estimated that the state had lost 671,000 jobs to automation between 1967 and 2014, more than it lost to domestic competition (such as from right-to-work states, which restrict the power of unions) and foreign trade combined.

But what makes the story in places like Toledo and the region around it hard for many politicians and even economists to understand is that the anxiety goes well beyond automation and the number of jobs. For many people, your job defines your life. The disruptions caused by robots and other technologies are deeply affecting the communities involved. These technological forces have joined many others—some cultural, some political—to create a generalized anguish that much is being lost. People have come to believe that they, their jobs, their communities, and the social contract that binds them to work and place and each other are under threat. And they're not wrong.

Just a few days after I spoke to Shrewsbery, much of the Jeep complex shut down. Hundreds were laid off. The layoffs were temporary while the company retooled to make a new Jeep truck. But if the truck doesn't sell and overall production volume drops at the complex, the good times will end. The robots, though, will still be working.

Good times for now

Local boosters argue that after a rough 30 years, Toledo is on its way back. The Jeep assembly plant is producing at full blast. A shiny new industrial park has opened for business on the old Cove site, practically underneath the one remaining smokestack, which was kept as a memorial. The old Libbey-Owens-Ford plant that made windshields for the Ford Model A and then for generations of cars over the next hundred years is rolling windshields off the line in Rossford, south across the Maumee River. Whirlpool, in the Sandusky County city of Clyde, is making thousands of washing machines per day. Toledo's downtown is showing signs of rejuvenation.

PREVIOUS SPREAD: J.D. POOLEY/GETTY IMAGES; JOE WILSSENS/FIAT CHRYSLER

Michigan, Wisconsin, and Pennsylvania would have swung to Clinton if robot adoption had been 2 percent lower.

A Jeep Liberty being built at the Toledo Assembly Complex.

But there's no euphoria, no "Happy Days Are Here Again" vibe. "It's almost too good right now," Doris Herringshaw, commissioner for neighboring Wood County, told me. She and her colleagues are "wary" about the future: "We have that feeling of 'Well, it's great now. Let's just hope we can keep it going that way.'"

Hard experience has taught Toledo. Drive along the avenue that skirts the north bank of the Maumee and you can see the grand mansions that testify to the prosperity of long-gone titans. Those titans turned Toledo into a cultural haven. Edward Libbey, a founder of Libbey Glass, provided the money to start the Toledo Art Museum, one of the nation's finest.

But those mansions have boarded windows now. Many are fronted by dead lawns and crumbled sidewalks. The streets of the once-elite neighborhood are so potholed that residents say the new mayor won election by promising to fix them. (Congresswoman Marcy Kaptur and her neighbor are planning to use their own gravel and tar to fill a hole in front of their homes.) Despite the recent economic good news, too many downtown buildings that used to be offices or warehouses still stand empty and in disrepair.

During the last recession, Chrysler and GM (which makes transmissions in the area) declared bankruptcy. In 2010, unemployment topped out at nearly 14 percent. The population of the Toledo metropolitan area, which includes surrounding counties, has been declining for years.

Regional leaders believe one reason the area suffered so badly was a failure to adapt to technology. So after the recession they placed new emphasis on closing the "skills gap." They wanted to create a "pipeline of people," Herringshaw says, who could maintain robots, work with robots, program computerized machines. A basic high school diploma was no longer adequate.

The kids in Robert Golden's Advanced Manufacturing Technologies program at Penta Career Center in Perrysburg are the beneficiaries of that effort. They work in a large, high-ceilinged space with short rows of drill presses and lathes, both manual and computer-controlled. A Fanuc LR Mate 200iD robot sits in a Plexiglas box awaiting student programmers and operators. Some of them have job offers before they even graduate. Golden, a genial man with cropped graying hair and safety glasses more or less permanently on his face, teaches skills that are in demand all over the region.

But what happens when the technology landscape that students are being trained to cultivate changes underneath their feet?

Few local leaders talk about artificial intelligence or smart robots. Gary F. Thompson, executive vice president and chief operating officer of Northwest Ohio Regional Growth Partnership, an economic development board, has of course heard of these new technologies and read a bit about them, but when he meets with mayors and other local leaders, nobody ever brings up what might happen if the next wave of automation turns the currently employed into expensive redundancies. Bruce Baumhower, president of Local 12 of the United Automobile Workers, serves on the partnership's board. He can't recall a time when the issue has been discussed.

When I traveled deep into rural Ohio to visit B-K Tool and Design in the village of Kalida, general manager Kevin Kahle told me his customers don't talk about AI either. It does not inform his business planning. That may seem odd, since B-K is one of the region's largest businesses helping manufacturers from Honda to small independents design and install robotic systems. But he's so busy adding new employees and trying to keep up with demand that there's no time to noodle over something as conceptually fuzzy as AI.

Such technologies still seem too esoteric and vague to influence the political or social structure of communities, especially when nobody can say for sure whether the labor market will change significantly. Meanwhile, the region has immediate needs. Potholes need filling, downtown needs rehabbing, and students need training to operate lathes in order to get the jobs on offer right now.

Some Toledo-area leaders might realize that a technological meteor is headed their way. But what are they supposed to do about something so unpredictable in its details? So they stress "lifelong learning." From the junior high kids in the robotics camp to the factory-floor employee, they all have to turn their lives into one long hustle to keep their heads above the incoming tide and whatever it might wash in.

Much of the work in the body shop at the Toledo Assembly Complex is automated. Here, a robotic arm moves the door of a Jeep Cherokee.

What Silicon Valley doesn't understand

Rickey slammed his hand down on the bar at Andy's Bar and Grill and said, "I couldn't believe it!" He works at an auto-related factory

in Wood County. When he and his buddy, who sat next to him drinking a post-shift beer, started at the plant, they had about 1,600 fellow workers, they said. Now there are about 600.

But that's not what had Rickey so agitated. "I mean, that shook me," he said of the 2016 election night.

Rickey is an African-American man who doesn't like to attribute anything to racism unless it's so obvious you'd have to be blind and deaf not to perceive it. Trump's campaign slogan rang hollow to him. "'Great again'?!" he shouted. "What's that mean? Wasn't so great for people who look like me!" But he "couldn't believe how many people voted for Trump."

Rickey being Rickey, he thought maybe the Trump phenomenon wasn't so much about race, exactly. When somebody in a red MAGA hat would talk to him, they'd talk about jobs. Rickey would point out that President Obama and the Democrats in Congress had favored bailing out Chrysler and GM, but he never got very far with that argument. The bailouts came almost a decade ago. All over again, people in the plant seemed so insecure about wages, retirement, jobs.

"We used to laugh at the robots," Rickey's buddy said. "When they first came in, they were so slow. We would sorta hurry and outproduce them. But one of the lines was about 18 people, and now they can run it with, like, five."

Rickey and his friend were echoing, almost word for word, two other men with whom I'd shared one-dollar beers in the Agenda Sports Bar, not far from the Toledo Assembly Complex. Both 30-year men who'd started at the Cove, they now worked at the complex. Both referred to management and agreed that "they want us out of there." One said, "If they could replace us with robots, they would. They doin' it faster and faster. You ain't gonna fool me! … They gonna replace us as fast as they can." Both also agreed that, despite the recommendation of UAW Local 12, "lots of people in our plant voted for Trump."

"Look, man," Rickey's friend said. "I'm a dumb guy. I am! I had a learning disability when I was in school. But I could do factory work. Factory work is what we did. Now robots do that job. What happens to people like me? People in the plant thinkin' somebody's gonna save 'em, like Trump. There ain't nobody gonna save 'em."

Rickey looked at me and said he tells his own children that if they wind up working in the plant, "then I failed as a father."

Every person I talked to in the Toledo region said technology was as unstoppable as the sunrise. The inevitability of it, and the uncertainty about what it would mean, weighed on them like lead blankets. Of the two men in the Agenda, one's grandfather and father had worked for Jeep. The other's father did. But legacy didn't mean anything anymore. You couldn't count on much for very long.

Kaptur listens to the people in her district and hears the same thing between the lines. "People feel very much alone," she says. "Vulnerable." Her voters have lived through globalized trade, outsourcing, recession, and the coming of robots. Soon it'll be AI. Meanwhile, defined pension plans are gone in favor of 401(k)s. More companies, like Fiat Chrysler, use more temp workers. New workers sign on to lower wage tiers. A working draft of the World Bank's World Development Report advised governments that "rapid changes to the nature of work put a premium on flexibility for firms to adjust their workforce, but also for those workers who benefit from more dynamic labor markets"—a fancy way of saying labor is disposable.

The effects are felt far beyond the jobs themselves. "Tribes of affection matter," Kaptur says. "Whether it's work-related, or a vets' organization, or church, neighborhood, neighborhood businesses—they're all evaporating. It's the disappearance of everything they've worked for. Their identity, really."

This is what Silicon Valley promoters of salves like universal basic income fail to understand. The engineers and programmers of the new machines seem to think they can buy off the displaced with a promise of cash. But many people don't work for money, not really. They need the money, and they want the money, but money alone isn't why anybody worked 40 years in the Cove. They stood on the line and welded or painted or bolted because they were auto workers in a country in which what you do is who you are, just as Shrewsbery is the Robot Doctor. They could look at a Wrangler, or a glass windshield, or a Whirlpool washer, and say "I made that."

Probably nobody voted for Trump just because of technology. But when people feel powerless, they'll gravitate toward any object, person, or belief they think might return some autonomy to them, or help them preserve what they fear they're losing.

"Nothing's permanent," Rickey told me. "We're in a transitional stage, and it scares me."

A few miles away from Andy's Bar and Grill, and adjacent to Interstate 75, a gigantic Bass Pro Shops Outdoor World built to resemble an enormous two-story timbered lodge was crowded with adults and families. The store offered every imaginable kind of fishing rod and reel, a mammoth aquarium stocked with freshwater game fish, deer heads mounted along a balcony, and clothing to suit almost any kind of expedition.

On the lower level, customers could shop in a separate "general store." A "fudge shop" tempted boys and girls of all ages. It was a village Main Street from a nostalgic dream of an America that no longer exists but feels ever more seductive as American life becomes increasingly unpredictable and unfair.

JEFF KOWALSKY/BLOOMBERG/GETTY IMAGES

"If they could replace us with robots, they would. They doin' it faster and faster. You ain't gonna fool me! ... They gonna replace us as fast as they can."

Brian Alexander is the author of Glass House: The 1% Economy and the Shattering of the All-American Town.

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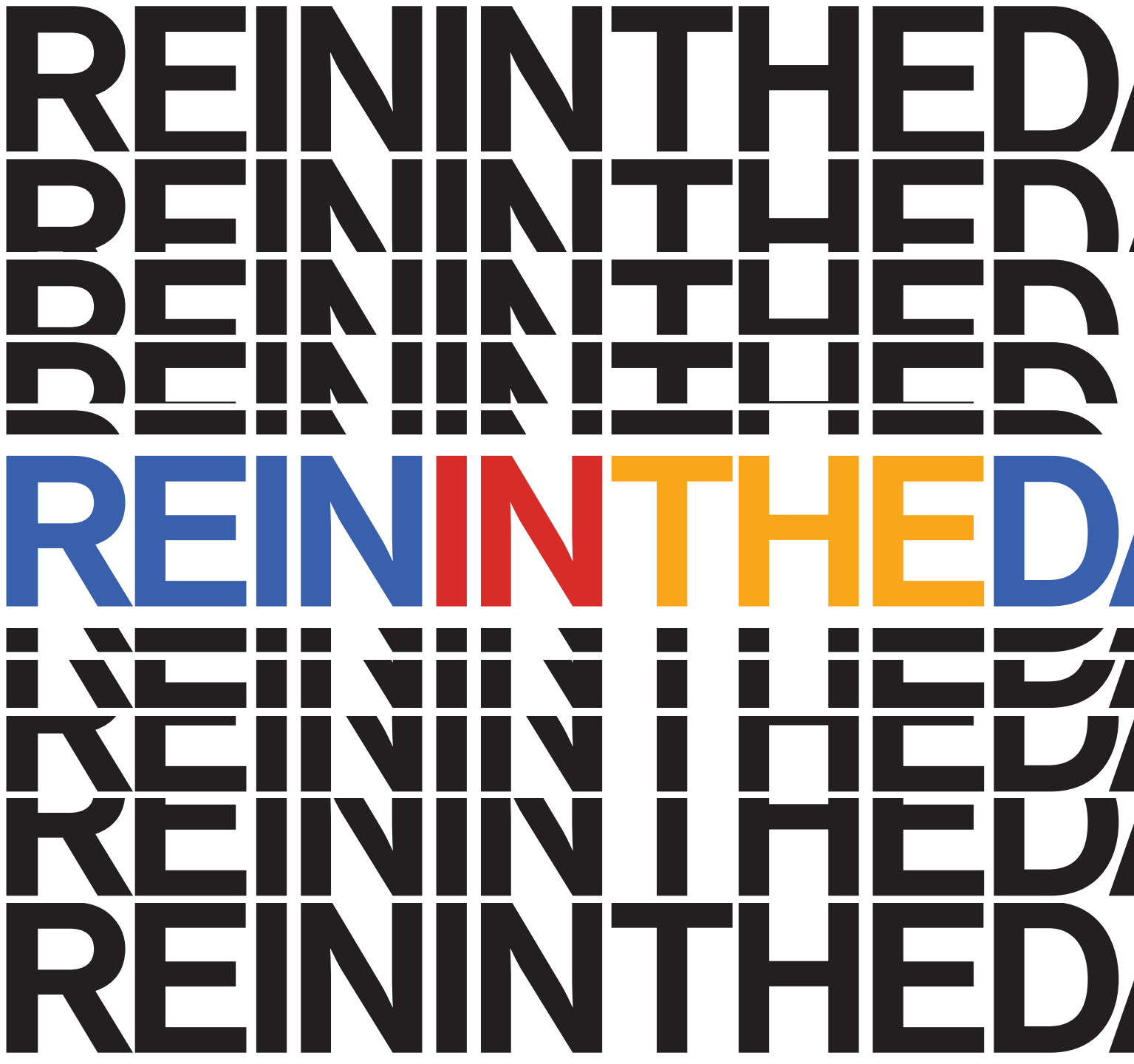
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Facebook, Amazon, and Google will resist attempts to restrain their market power. But for the sake of our collective prosperity and our personal privacy, it's a fight we can't afford to lose.

By Martin Giles

When Mark Zuckerberg appeared before Congress earlier this year to discuss how the now-defunct political-data company Cambridge Analytica acquired data of up to 87 million Facebook users without their knowledge or consent, one of the few pointed questions came from Lindsey Graham, a Republican senator from South Carolina. "Who's your biggest competitor?" Graham demanded. After Zuckerberg replied that Google, Apple, Amazon, and Microsoft all had some overlap with various Facebook products, Graham chafed at the answer.

"If I buy a Ford and it doesn't work well and I don't like it," pressed the senator, "I can buy a Chevy. If I'm upset with Facebook, what's the equivalent product I can go sign up for?" A bit later, the senator came back to the theme when he asked if the social network's CEO thought Facebook was a monopoly. "It certainly doesn't feel like that to me," said Zuckerberg.

But to many people, it does. With over two billion users, the company is the colossus of social networking, dwarfing rivals like Twitter and Snapchat. Along with Amazon and Google, which is owned by holding company Alphabet, it dominates the internet landscape. Apple and Microsoft are often mentioned in the same breath as these tech giants, but their business lines are more varied and less internet-centric—enterprise software in Microsoft's case, phones and other devices in Apple's.

There's another key difference too. Facebook, Google, and Amazon all have business models that require them to scoop up large amounts of data about people to power their algorithms, and they derive their power from this information (see "Let's make private data into a public good," page 74). It's the sheer scale and sophistication of the data-collection empires they've built that make them so distinctive.

For the past decade or so, these three firms have had a relatively smooth ride to the top. Their cornucopia of services, often provided for free, made them immensely popular and turned them into some of the most valuable businesses in the world. Their combined market capitalization of some $2 trillion at the end of May was roughly equal to the GDP of Italy. Now, however, debates are in full swing on both sides of the Atlantic about how to deal with their dominance.

Déjà vu, but different too

The history of technology has seen singularly powerful corporations before—think of IBM and its reign in mainframes, and Microsoft, the undisputed heavyweight in the PC era. What's different this time is the enormous influence the big firms have over so many parts of daily life, and the troubling issues this raises.

The Cambridge Analytica affair is just the latest in a long line of data scandals that have dogged Facebook. In 2009 it made information about users public without their permission; a few years later, Facebook researchers deliberately manipulated News Feed posts seen by almost 700,000 people to test whether they could influence users' moods without their knowing. (Yes, was the disturbing answer.) Google, too, has had privacy runins, and in 2012 it was fined by regulators in America for circumventing default settings in Apple's Safari web browser to place ad tracking software on people's computers without their knowledge.

These incidents may appear isolated, but they fit into a bigger picture. Like the oil barons at the turn of the 20th century, the data barons are determined to extract as much as possible of a resource that's central to the economy of their time. The more information they can get to feed the algorithms that power their ad-targeting machines and product-recommendation engines, the better. In the absence of serious competition or (until Europe's recently introduced General Data Protection Regulation) serious legal constraints on the handling of personal data, they are going to keep undermining privacy in their push to know as much about their users as they possibly can.

Their dominance is allowing them to play a dangerous and outsize role in our politics and culture. The web giants have helped undermine confidence in democracy

45%

of American adults now get at least some of their news from Facebook.

by underestimating the threat posed by Russian trolls, Macedonian fake-news farms, and other purveyors of propaganda. Zuckerberg at first dismissed claims that disinformation on Facebook had influenced the 2016 election as "pretty crazy." But Facebook itself now says that between June 2015 and August 2017, as many as 126 million people may have seen content on the network that was created by a Russian troll farm.

Facebook and Google have built new tools for identifying disinformation and vetting advertisers, but it's not yet clear how effective these will be. Even with news that is not clearly fake, researchers have shown that Facebook's content-recommendation algorithms tend to serve up stuff that reinforces people's prejudices. This might be happening even if the social-media industry were more fragmented. But the immense reach of platforms like Facebook has undoubtedly magnified the impact: according to a Pew Research Center study published last year, 45 percent of American adults now get at least some of their news from Facebook.

Then there's the considerable market power they've built up, which has created turmoil in some industries and stifled innovation in the areas they dominate. Facebook and Google now amount to a digital advertising duopoly: they pocket three out of every four dollars spent on digital advertising in America, and they control 84 percent of global spending on such ads, excluding China. Google controls almost 80 percent of search advertising revenue in America and has a huge share in many other countries.

Amazon, meanwhile, accounts for over 83 percent of e-book sales in the US and nearly 90 percent of online print sales. The companies' dominance has plunged the media and book publishing industries into turmoil: between 2006 and 2016, ad spending in US newspapers fell by almost two-thirds, and much of that money ended up in Facebook's and Google's hands. Amazon has also become a powerful online gatekeeper for many other kinds of online sales, and it handled around 44 percent of all e-commerce transactions in the US last year.

Their platforms give the data barons an unprecedented amount of control over what we see, read, and buy. Jonathan Taplin, the director emeritus of the Annenberg Innovation Lab at the University of Southern California, argues in *Move Fast and Break Things*, his book about the power of the internet giants, that rebel artists have long had to deal with "suits" who control distribution of their work. But the rise of companies like Facebook and Amazon has increased the stakes immeasurably. "The concentration of profits in the making of arts and news," he writes, "has made more than just artists and journalists vulnerable: it has made all those who seek to profit from the free exchange of ideas and culture vulnerable to the power of a small group of … patrons."

The data barons like to say that claims about their dominance are overblown. During his congressional testimony, Facebook's Zuckerberg noted that the average

Facebook and Google get $3 out of every $4 spent on digital ads in the US.

Their platforms give the data barons an unprecedented amount of control over what we see, read, and buy.

American uses eight different communication and social apps. What he neglected to mention was that the social network owns several of the most popular ones, like its Messenger service and Instagram. Google argues that companies like Amazon and Facebook effectively compete with it in search by helping people find information, but its real competitors are dedicated search engines like DuckDuckGo and Microsoft's Bing, which have relatively small market shares. Amazon can point to the fact that there are lots of companies offering e-commerce services, and that it competes with brick-and-mortar retailers, but its dominance in areas like book publishing is impossible to ignore.

The data barons' power makes startups extremely reluctant to challenge them, and makes venture capitalists wary of backing the few mavericks that do. Speaking at an antitrust conference earlier this year, Albert Wenger, a managing partner at Union Square Ventures, said that one of founders' top priorities these days is to avoid the internet giants' "kill zones," the areas in which they are capable of crushing any competition. And those zones are only going to grow as the web companies plunge into more businesses. Breakthrough ideas often come from startups rather than from large firms, so this could be depriving us of important innovations.

Special effects

It wasn't supposed to be this way. By lowering barriers to entry and making it easy for consumers to switch services with a few clicks of a mouse, the internet in its early days seemed designed to ensure that digital empires would promptly be besieged by fleets of rebel startups. So why didn't that happen?

Part of the answer involves one of Silicon Valley's favorite buzz phrases: "network effects." Many online products and services become more valuable as more people use them. Buyers flock to Amazon because they know they'll find lots of sellers—and hence lots of choices; people join Facebook because their friends are there. The US internet giants have been particularly skilled at harnessing these effects, as have Chinese firms like Alibaba and Tencent, which have become similarly dominant in their home market.

Thanks to network effects, Facebook, Google, and Amazon have been able to harvest oceans of data, which they use to continually refine their products and services. That, in turn, wins them even more users, which yields even more data, and so on. When other businesses show

When the following companies were acquired by the data barons:

signs of succeeding in their markets, the data barons have often swooped in to buy them using their high-priced shares or vast cash reserves. Facebook bought Instagram and WhatsApp; Amazon picked up Zappos and Quidsi, two fast-growing online retailers; and Google acquired Waze, which was on the road to becoming a serious competitor to Google Maps. Sometimes consumers don't even notice these deals: after the Cambridge Analytica scandal broke, some Facebook users posted that they intended to move to Instagram in protest, clearly unaware it belonged to Facebook.

The reason the data barons have been so aggressive is that they are all too aware of how network effects can be turned against them by rivals and used to threaten their data-driven monopoly power.

Why haven't antitrust regulators blocked deals to promote competition? It's mainly because of a change in US antitrust philosophy in the 1980s, inspired by neoclassical economists and legal scholars at the University of Chicago. Before the shift, antitrust enforcers were wary of any deals that reinforced a company's dominant position. After it, they became more tolerant of such combinations, as long as prices for consumers didn't rise. This was just fine with internet companies, since most of their services were free anyway. Critics say trustbusters exercised too little scrutiny. "Just because the web companies offer products for free doesn't mean they should get a free pass," says Jonathan Kanter, an antitrust lawyer at Paul Weiss.

They've become so dominant by developing products and services that many of us want to use.

Move fast and challenge things

Another reason antitrust officials have struggled with the internet giants' power is that they haven't really appreciated how network effects can breed dominant market positions. At least Europe's watchdogs have been tougher on anticompetitive behavior. Last year the European Union's antitrust authority fined Google 2.4 billion euros ($2.7 billion) for unfairly favoring its own price-comparison shopping service in search results, depriving rivals of traffic. (The firm says it did nothing wrong and is appealing the ruling in court.) The EU is also investigating claims from rivals that Google uses its Android mobile operating system and AdSense advertising service to unfairly suppress competition.

In the US, the big web companies had lobbying clout and close links to the Obama administration, which may have given them an easier ride. But their standing with the government could be about to change: Steven Mnuchin,

84%

of global spending on digital ads (outside China) goes to Google and Facebook.

Amazon accounts for about 85% of US print book sales.

Making the legal case for breakups will be hard because the internet giants don't fit the stereotype of rapacious monopolists.

the US Treasury secretary, has urged the Department of Justice to take a hard look at the market power of big tech firms, and Joseph Simons, the new chairman of the Federal Trade Commission, which also has antitrust powers, said in his Senate confirmation hearing that he'd watch "big and influential" companies in Silicon Valley carefully. "I'm very optimistic that by the end of the year we'll have a major investigation or two out there," predicts Luther Lowe, the head of public policy at Yelp, a service that collects local reviews about things like restaurants and repair shops. Yelp has been locked in a long-running war of words with Google, which it says unfairly favors its own reviews in search results. Google rejects the charge.

If Lowe is right, the big internet firms could end up spending more time in American courts. But thanks to their vast wealth, fining them for any transgressions won't diminish their power.

One radical solution would be to break them up, just as the US government splintered the dominant Standard Oil monopoly in the early 1900s. Some progressive advocacy groups in the US have been running online campaigns with slogans like "Facebook has too much power over our lives and democracy. It's time for us to take that power back," and calling on the FTC to force the social network to sell Instagram, WhatsApp, and Messenger to create competition.

Facebook isn't the only company in their sights. Earlier this year, Lina Khan, a researcher at the Open Markets Institute, one of the organizations behind the Facebook campaign, argued in a paper that because Amazon has become so dominant in e-commerce, it should be regulated and made to choose between being a seller of goods itself and running the digital platform it and other merchants use to reach customers. If it chose to be a platform, it would, among other things, have to spin off Whole Foods, the US supermarket chain it bought last year.

Making the legal case for breakups will be hard, though, because the internet giants don't fit the stereotype of rapacious monopolists that raise prices and squeeze investment. They manipulate markets in a different and seemingly more benevolent way. They've become so dominant by developing products and services that many of us want to use. And they gain their immense power through collecting data about our online activity.

Still, just the threat of corporate dismemberment can have a salutary effect. In the 1990s the Department of Justice tried to force Microsoft to stop bundling its Internet Explorer web browser with its dominant Windows operating system, saying it was giving the browser an unfair advantage over Netscape. The government ultimately failed to get Microsoft broken up, but the bruising battle made the company more cautious about wielding its power to block small firms in emerging markets like online search—a fact that helped Google to flourish. (See a Q&A with Gary Reback, the lawyer who got the government to take on Microsoft, on page 72.)

Bridging the data chasm

So how to curb the power of the data barons? Rather than waiting for legal battles that may or may not foster more competition, we urgently need to find ways to bolster rivals. That means reducing the vast chasm between the amounts of information held by the web giants and the rest. Regulation can help here: Europe's new data privacy regime requires companies to hold people's data in machine-readable form and let them move it easily to other businesses if they want to. This "data portability" rule will allow startups to get hold of more data quickly.

If one or another of the data barons is found guilty of anti-competitive behavior, a settlement should include a requirement that they have to share some of their data with rivals. Google, for instance, could be forced to hand over some search data that other firms working on search engines could use to train them, and Facebook could be made to share some of its "social graph" data on people's online relationships. The best way to do this (while protecting people's privacy) would need to be carefully thought out, but it would have a bigger impact than large fines, which the internet companies can easily pay.

Some argue that we need to think much more boldly—and not just with the big internet companies in mind. Viktor Mayer-Schönberger, a professor at the University of Oxford, has proposed what he calls a "progressive data-sharing mandate" that would apply to all businesses. This would require a company that has passed a certain level of market share (say, 10 percent) to share some data with other firms in its industry that ask for it. The data would be chosen at random and stripped of all personal identifiers. Intuitively, the idea makes sense: the closer a company gets to dominating its market, the more data it would have to share, making it easier for rivals to compete by building a better product.

Mayer-Schönberger's suggestion may be hard to make work, but tackling the power of the internet giants will require novel approaches. It will also require a more muscular merger policy, one that looks beyond the narrow test of whether a proposed acquisition would raise prices to consider what it would do to future competition. We're going to need to block not just large deals that would cement the web giants' dominance but also smaller ones capable of eliminating competitors that might go on to challenge them. Carl Shapiro, an antitrust expert at the University of California, Berkeley, has said this could lead to some "false positives," blocking acquisitions of young companies that never do turn into real threats to a Google or a Facebook. But he says this might be a price worth paying in order to stimulate more competition.

The need for such moves is even more pressing now that we're heading deeper into the artificial-intelligence era. AI feeds on massive amounts of data to gain its power. So the data barons' vast data reserves give them a head start in training AIs that will run all kinds of devices and systems, from driverless cars to software that decides whether or not you should get a loan. That's going to make it harder than ever for other firms to catch up.

The prominent AI investor Kai-Fu Lee noted this in an article in the *New York Times* last year: "The more data you have, the better your product; the better your product, the more data you can collect; the more data you can collect, the more talent you can attract; the more talent you can attract, the better your product." It's no coincidence that Facebook, Google, and Amazon are intent on gaining as much data as possible and securing some of the brightest AI minds on the planet to work for them.

Increasingly, the AI-powered, voice-activated assistants these firms are building will be in our cars, homes, and offices, as well as on our phones. We'll expect them to deliver "the" answer to questions, rather than the smorgasbord of suggestions that often gets served up today. The companies whose algorithms decide what those answers will be will have an even more powerful influence over us and over the global economy. And to ensure that they hold on to their dominance, Facebook, Google, and Amazon will soon be vacuuming up even more data about us.

During his congressional testimony, Zuckerberg accepted that new rules are going to be needed to govern his company and others. "So I think the internet is becoming increasingly important in people's lives," he said, "and I think we need to have a full conversation about what is the right regulation, not whether it should or shouldn't be." To create those rules, we urgently need to focus on the source of the internet giants' power and the dangers that it entails. The sooner we find smart ways to diminish the firms' dominance of our data, the better.

2.4 billion

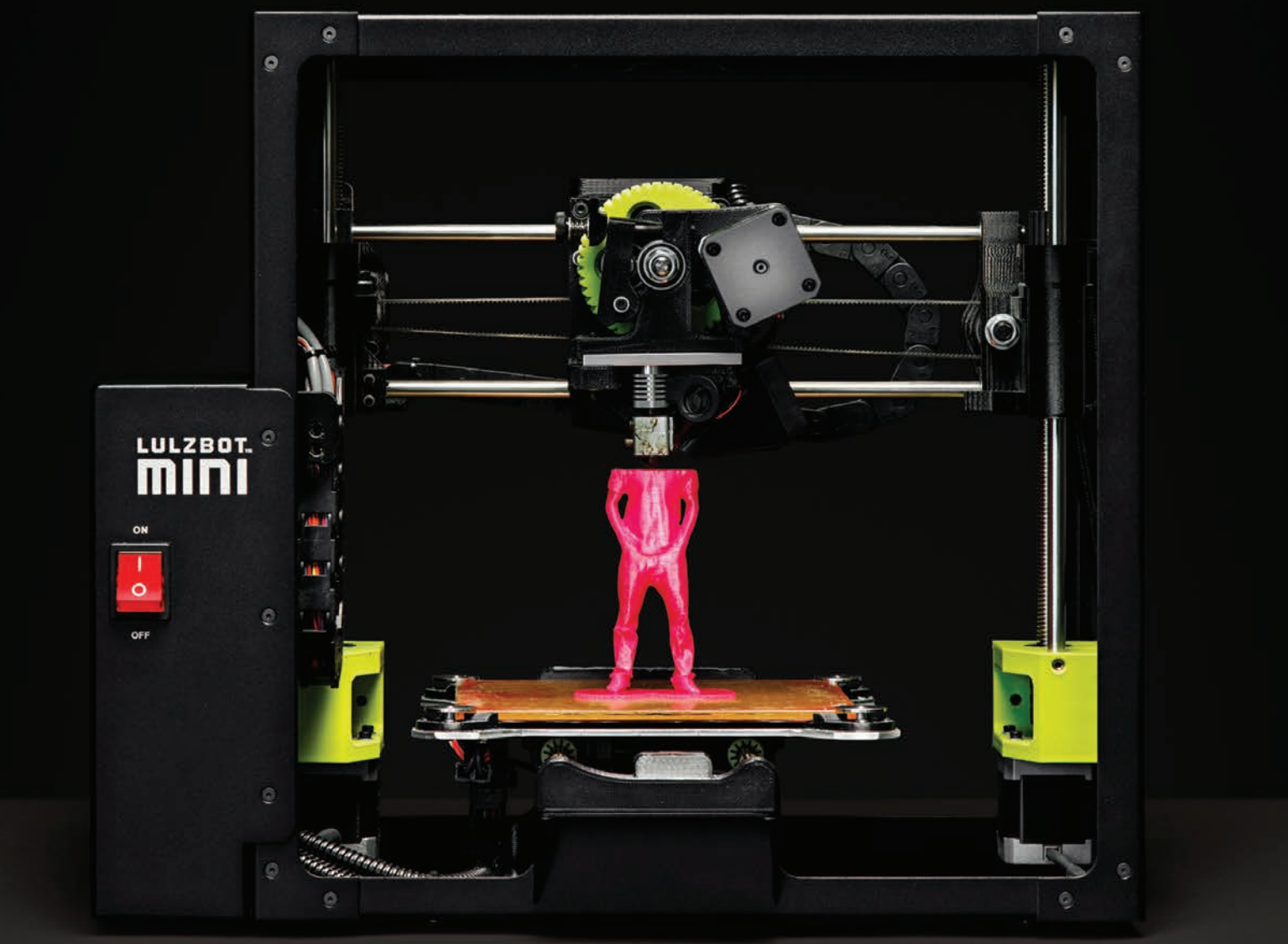
Amount, in euros, the EU fined Google last year for alleged anticompetitive behavior.

Martin Giles is MIT Technology Review's San Francisco bureau chief.

Confessions of an accidental job destroyer

Behind every piece of automation is a human who made it happen.

By Erin Winick
Photograph by Bob O'Connor



I expected my summer engineering internship to include things like updating old 3-D models, creating part designs, and learning the ins and outs of how a company works. I didn't expect it to involve learning to make my colleagues obsolete.

It was the summer after my sophomore year of college, at a company in Southern California. At the beginning of the internship, my manager asked me to implement 3-D printing to streamline a complicated mold-making process. I have long been obsessed with 3-D printing (I own two machines myself), so I was thrilled to introduce it into the business.

First I had to look at how the company currently made molds. So I sought out the man who did it. (We agreed not use his real name, so I'll call him Gary.) He was the only one who knew about the costs, the dimensions, and why these molds were made the way they were. The project wouldn't work without him.

As he described the process and his role in it, I realized that making molds was Gary's sole responsibility. He had spent over 30 years perfecting these tools and parts. If my project succeeded, I would be making him redundant.

At first he was friendly and eager to talk. But as I explained the goals of my project, his tone changed. He was still willing to talk, though, after venting a bit about our bosses and the company.

Throughout my internship, we built a sort of … relationship. I asked questions; he provided information. The conversations involved a lot of me smiling and nodding and acting as a sounding board. I seemed like one of the few people who cared about what he had to say. Since we both knew that my project could cost him his livelihood, I felt I at least owed him that attention.

Each time we spoke, I was closer to making a working product—and more nervous about telling him how things were going. I felt that by doing so, I was letting him know how close he was to losing his job. A few times I suggested he retrain to learn how to operate the 3-D printer. That seemed far-fetched to him. He didn't think the company would be willing to invest in a worker his age.

I had built a workable prototype by the end of the summer. To show off my progress, I arranged a demo for my bosses, and I invited Gary. The higher-ups praised my creation and openly appreciated the money it would potentially save. But it felt ominous to flaunt my work in front of the guy whose job it threatened. I was proud of what I had made, but I knew what the repercussions could be if they decided to use it.

I left that internship without knowing the outcome. At the time I was happy to embrace the ignorance. I left the moral quandaries about the consequences of technological innovation to the execs.

But I still wondered what had happened to Gary. Earlier this year, I contacted him to finally find out.

The company had used my project. It was improved until it was ready to hit the factory floor. When it did, Gary was assigned to a new area. However, he was unhappy in his new role and with the business in general. He retired—after 34 years with the company.

Essentially, although he wasn't laid off, he lost his job as a result of my work.

In society's narrative of the war between robots and humans, I'm probably the bad guy. But human vs. robot isn't always good vs. evil. Automation creates new roles for people. Humans will be the ones to install and create our new robotic coworkers. According to the International Federation of Robotics, the average proportion of robots to workers worldwide is 74 to 10,000, and this number is rising. The robotic workforce grew by 9 percent in Asia in 2017, with 631 robots per 10,000 employees in South Korea. Yet by 2030, according to predictions from McKinsey, technology spending alone will create 20 million to 50 million new jobs, some of which will introduce tech and tools like those robots to workplaces.

If you, too, are a job automator, or will be someday, here's my advice: talk to the people whose jobs you are automating. It's going to be uncomfortable, but they probably want to tell you their point of view. Dismissing them can reinforce the us-against-them mind-set and create opportunities for miscommunication. When I talked to Gary for this story, he told me the company had taken "a very aggressive stance with [him] and some other employees in similar positions" after I left. "I assumed, wrongly, that I would have an opportunity to follow along with the evolution of the process," he said.

While I did eliminate Gary's role, my 3-D printer created opportunities at the company for workers who knew how to run the new machines. Gary said that was one of his biggest takeaways: "I learned that you cannot allow yourself to get complacent. You must stay current with new processes and technology even if it means doing it on your own time and at your own expense."

Connecting with him again was a cathartic but strange experience. Gary said he was surprised—pleasantly!—to hear from me. He moved states and is working in customer service now. I asked him what his initial reaction was when I approached him about the project all those years ago. "I was excited to find that somebody was willing to discuss what was happening," he said. "The 'official position' of the company was that there was no attempt to change anything about how things were being done."

Communication might not be enjoyable for either party, but it is necessary. People are a crucial part of the automation process. The robots won't take over without us.

Erin Winick is MIT Technology Review's associate editor for the future of work.

In society's narrative of the war between robots and humans, I'm probably the bad guy.

Free money's big test

A Canadian province is giving people a basic income, no strings attached—revealing both the appeal and the limitation of the idea.

By Brian Bergstein

Photographs by Jennifer Roberts

Fresh produce

Dana Bowman, 56, expresses gratitude for fresh produce at least 10 times in the hour and a half we're having coffee on a frigid spring day in Lindsay, Ontario. Over the many years she scraped by on government disability payments, she tended to stick to frozen vegetables. She'd also save by visiting a food bank or buying marked-down items near or past their sell-by date.

But since December, Bowman has felt secure enough to buy fresh fruit and vegetables. She's freer, she says, to "do what nanas do" for her grandchildren, like having all four of them over for turkey on Easter. Now that she can afford the transportation, she might start taking classes in social work in a nearby city. She feels happier and healthier—and, she says, so do many other people in her subsidized apartment building and around town. "I'm seeing people smiling and seeing people friendlier, saying hi more," she says.

Jim Garbutt sees moods brightening, too, at A Buy & Sell Shop, a store he and his wife run on Lindsay's main street. Sales are brisker for most of what they sell: used

Dana Bowman in her home.

furniture, kitchen items, novelties. A Buy & Sell Shop is the kind of place where people come in just to chat—"we're like Cheers, without the alcohol," Garbutt says—and more and more people seem hopeful. "Spirits are up," he says.

What changed? Lindsay, a compact rectangle amid the lakes northeast of Toronto, is at the heart of one of the world's biggest tests of a guaranteed basic income. In a three-year pilot funded by the provincial government, about 4,000 people in Ontario are getting monthly stipends to boost them to at least 75 percent of the poverty line. That translates to a minimum annual income of $17,000 in Canadian dollars (about $13,000 US) for single people, $24,000 for married couples. Lindsay has about half the people in the pilot—some 10 percent of the town's population.

People far beyond Canada will be watching, too, because a basic income has become Silicon Valley's favorite answer to the question of how society should deal with automation.

The trial is expected to cost $50 million a year in Canadian dollars; expanding it to all of Canada would cost an estimated $43 billion annually. But Hugh Segal, the conservative former senator who designed the test, thinks it could save the government money in the long run. He expects it to streamline the benefits system, remove rules that discourage people from working, and reduce crime, bad health, and other costly problems that stem from poverty. Such improvements occurred during a basic-income test in Manitoba in the 1970s.

People far beyond Canada will be watching closely, too, because a basic income has become Silicon Valley's favorite answer to the question of how society should deal with the massive automation of jobs. Tech investors such as Facebook cofounder Chris Hughes and Sam Altman, president of the startup incubator Y Combinator, are funding pilot projects to examine what people do when they get money with no strings attached. Hughes's Economic Security Project will pay for 100 people in Stockton, California, to get $500 a month for 18 months. Y Combinator ran a

Downtown Lindsay, Ontario.

small-scale test in Oakland, California, last year; beginning in 2019 it will give $1,000 a month to 1,000 people over three to five years, in locations still to be determined.

This momentum figures to keep building as AI and robotics make even more inroads. Legislators in Hawaii are beginning to study the prospects for a basic income. The lawmaker who has led the effort, Democrat Chris Lee, worries that self-driving cars and automated retail checkout could be the beginning of the end for a lot of human labor in Hawaii's service-based economy. If machines can handle tasks in tourism and hospitality, Lee says, "there is no fallback industry for jobs to be created in."

But there's an important difference between that vision for a basic income and the experiment in Ontario. The Canadians are testing it as an efficient antipoverty mechanism, a way to give a relatively small segment of the population more flexibility to find work and to strengthen other strands of the safety net. That's not what Silicon Valley seems to imagine, which is a universal basic income that placates broad swaths of the population. The most obvious problem with that idea? Math. Many economists concluded long ago that it would be too expensive, especially when compared with the cost of programs to create new jobs and train people for them. That's why the idea didn't take off after tests in the 1960s and '70s. It's largely why Finland recently abandoned a basic-income plan after a small test.

If any place can illuminate both the advantages of basic income and the problems it can't solve, it will be Lindsay. The town is prosperous by some measures, with a median household income of $55,000 and a historic downtown district where new condos and a craft brewery are on the way. But that masks how tough it is for a lot of people to get by. Manufacturing in the surrounding area, known as the Kawartha Lakes, has declined since the 1980s. Many people juggle multiple jobs, including seasonal work tied to tourism in

the summer and fall. Technology is part of the story too: robots milk cows now.

Basic income as a social equalizer

The Olde Gaol Museum is indeed an old jail, but it's also a showcase for things that reveal the texture of Lindsay's history—uniforms that nurses from town wore in France during World War I; tools and maps used by railway workers when this was a hub for eight railroad lines; 19th-century paintings by a local artist who depicted the timeless regional pastimes of canoeing and fishing. When curatorial assistant Ian McKechnie gives me a tour, he stops and plays a lovely tune on a foot-pumped organ called a harmonium that was made in Ontario more than a hundred years ago.

McKechnie, 27, has worked at the museum for seven years and is devoted to it. Unlike his previous job, when he was briefly a laborer at a goat cheese factory, it offers a chance to be creative and connect with many people in the community. He doesn't just give tours: he researches and organizes exhibits and writes supporting materials. But on the day we meet, the museum is not paying him to be at work, and therein lies a story about why he and the Olde Gaol's operations supervisor, Lisa Hart, both signed up for the basic income.

The museum gets almost all its revenue from grants, and one just expired. The manager of the museum recently left, and

A basic income has allowed Bowman to add fresh vegetables to her diet.

so it falls largely to McKechnie and Hart to keep things going until another grant comes in. Even when it does, these won't be lucrative jobs—perhaps $20,000 a year for McKechnie's. They could find positions in the area that pay more, but both would much rather continue their labor of love at the museum. Leaving now might undercut its momentum toward a more sustainable future, which could include a new cultural center that would connect the museum with a local art gallery.

Thanks to the basic-income trial, both can afford to stay on with the museum. And in the meantime, Hart says, she will no longer put off buying new eyeglasses. The basic income "allows you to spend time on something that's valuable," she says. "It's very sad to walk away from something where you're valued and doing something meaningful for the community because it just can't pay you a lot."

This highlights an intriguing aspect of basic income: it functions in different ways for different people. The way Hart describes it, it's fuel for cultural development. For Dana Bowman, who might now take classes in social work and regularly volunteers at a community garden, it's a food subsidy, an educational grant, and a neighborhood improvement fund all in one. For a married couple who own a health-food restaurant that barely covers its costs, it's a small-business booster. A man who hurt his back working in a warehouse told me he hoped it could augment his employer's disability payments. A student who was about to graduate from a technical college and had a job lined up said he planned to use the extra income to pay down school loans and start saving for a house.

For McKechnie, the basic income is something broader: a social equalizer, a recognition that people who make little or no money are often doing things that are socially valuable. "It gives one the

Visits to the community gardens have become part of Bowman's routine.

While giving poor people money helps them, it still leaves unanswered difficult questions about the impacts of automation and globalization. What will it take to ensure that entire regions aren't left behind?

The apartment complex where Bowman lives, and her living room.

assurance that the work you're doing is not in vain, even though you're not working in a bank or doing other things that are considered part of a career," he says.

Part of a safety net

Even if a basic income turns out to be a flexible and efficient government program, it's not clear that it would be a great way to respond to technological unemployment. Over and over again, people in Lindsay told me it won't reduce people's demand for jobs.

As a practical matter, the Ontario trial doesn't pay enough to eliminate most people's need to work or to rely on family for support. But even if a richer payout were feasible, that wouldn't change the philosophy of the program. Basic-income supporters want to improve the odds that people will take better care of themselves and their families. They want a humane and dignifying way of helping people who simply can't work. But they also argue that most people generally want and expect to work. "It's not supposed to be welfare for people displaced by technology," says one of the basic-income advocates, Mike Perry, who runs a medical practice in Kawartha Lakes.

Moreover, while giving poor people money helps them, it still leaves urgent and difficult questions unanswered about the impacts of automation and globalization. What will it take to ensure that entire regions aren't left far behind economically? What can be done to boost the supply of good, steady jobs? Basic income "is only the beginning," says Roderick

Benns, former vice chair of the Ontario Basic Income Network. "It's not just 'cut a check and get on with building the corporatocracy.' We have to ask what else we are doing as a society to get people to reimagine what they can do with their lives."

Benns, the author of several books, grew up in Lindsay. Until recently, he and his wife, Joli Scheidler-Benns, lived three hours away, but the pilot is so important to them that they moved back so he can chronicle it in a new publication called the *Lindsay Advocate* and she can do research for her PhD on the subject at York University. After Benns describes how basic income should augment job training and other social programs, Scheidler-Benns, who is originally from Michigan, nods and then adds: "I don't see how it could work in the US."

After all, she says, Canada does many other things to strengthen its safety net and reduce inequality. For one, it has universal health care. School funding in Ontario is primarily allocated at the province level rather than being heavily dependent on local property taxes, as it is in the US. Canada also traditionally spends about 1 percent of its GDP on workforce-development programs, according to the Organization for Economic Cooperation and Development. That's about half of the proportion in other advanced countries, but it still dwarfs the US figure, which is about 0.3 percent.

A basic income could help people break out of poverty that has beset families for generations. Still, how do you prepare students for a world in which more and more tasks are being automated?

Funding a different mind-set

Tony Tilly is the outgoing president of Fleming College, which specializes in preparing people in Kawartha Lakes for careers in both white-collar work and trades. About half the students don't come right from high school; they've already been in the workforce and hope to learn a new skill.

He supports a basic income because he thinks it could help people break out of poverty that has beset their families for generations. But even if the program continues past the three-year trial period, Fleming's essential challenge would remain: how to prepare students for a world in which more and more tasks are being automated.

Fleming is still priming its graduates to work in traditional strongholds of the regional economy: jobs tied to the environment and natural resources, infrastructure development, mining, construction, and government. But the school is trying to

The Olde Gaol Museum keeps going thanks to the help its staff gets from the basic-income project.

instill a different mind-set from the one students had when Tilly became its president 14 years ago. They now get more emphasis on so-called soft skills: teamwork, problem-solving, personal interaction. Above all, he says, they need to know "not only how to do some particular job but how to contribute overall to the success of an organization, whether it's a manufacturer or a provider of social services."

If the basic-income plan works as expected, Fleming might get even more students than it otherwise would. Dana Bowman could be one of them.

It's been years since she last had a paying job, as a receptionist. She has been on disability for a variety of ailments, including skin cancer and arthritis. But she feels she is up to doing some part-time work. In 2015, two years before the basic-income trial, Bowman asked a case worker if she could get help paying for transportation to a Fleming campus that offers classes in social work. The official said that would lead to cuts in other benefits Bowman relied on. The message Bowman says she got was: "You're unemployable. You're not worth investing in."

In contrast, the basic-income plan ensures a minimum for her without micromanaging how she spends it. For every dollar that recipients earn above the minimum, their payout from the province will be cut by 50 cents, but no one is made worse off by working.

Even being able to consider that prospect, Bowman says, has been good for her. "I don't feel 'less than.' I feel 'equal to.' Not feeling guilty walking down the street, thinking, 'I didn't do enough today,'" she says. "People want to do something. People aren't inclined to do nothing."

Brian Bergstein is a contributing editor at MIT Technology Review and the editor of Neo.Life.

Going driverless in the city of cars

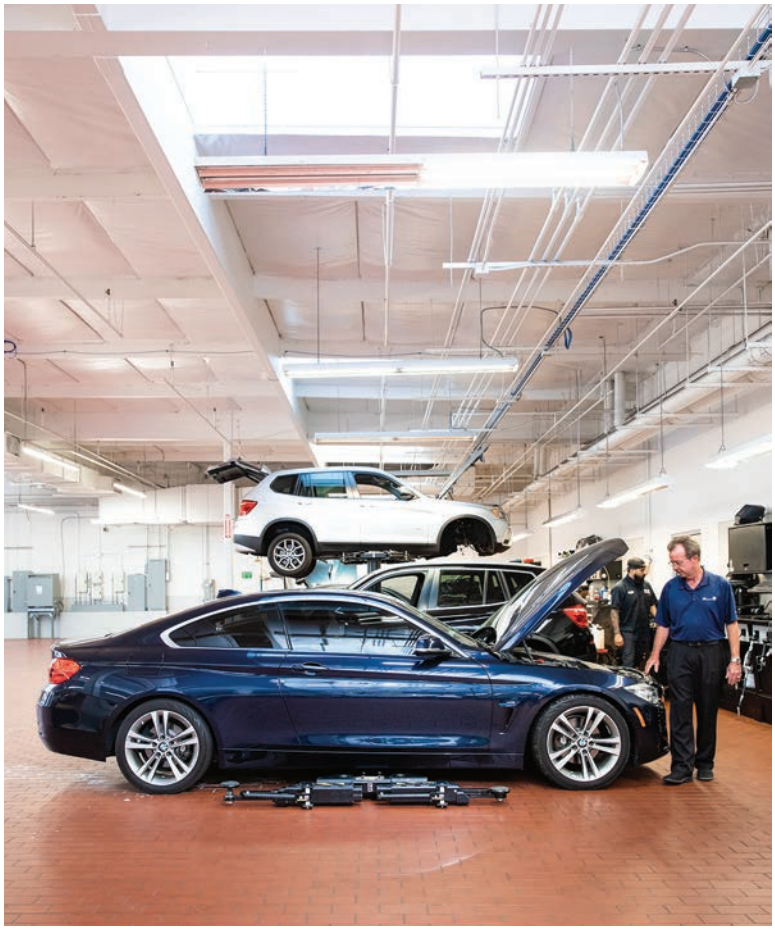
What will the adoption of shared autonomous vehicles do to the urban fabric of much of America?

By Ed Finn

Photographs by Brandon Sullivan


Courtesy
CHEVROLET
MEMORIAL DAY TENT SALE

Joe Helms, a service advisor at Chapman BMW on East Camelback Road in Phoenix.



THE CAR CULT

Sitting in the BMW dealership waiting for a flat to be replaced, I realize I've driven over 100 miles and spent five hours behind the wheel this week. And it's only lunchtime on Wednesday. In Phoenix, I am living the life this city has designed for me.

A sprawling grid fueled by swooping highways and generous arterial roads, the Phoenix metropolitan area is a gargantuan expression of the car culture that defines the urban experience for most Americans. To use this space, you need a vehicle. Anything else effects your passive or active exclusion from a host of activities and, more broadly, from the culture itself. You might choose to live downtown in one of the few patches of walkable urban space, but your access to groceries, drugstores, and other amenities will be severely limited. To meet friends, to send children to school, to attend a concert or a movie, is to buy into car culture and its attendant traffic jams, parking-space hunts, and maintenance responsibilities for a vehicle that is expensive to purchase and rapidly loses value.

Camelback Road, one of those major arteries, is a 33-mile temple to this cult of the car. Dealerships, auto repair shops, strip malls, and car washes, all ringed by vast parking lots, line a six-lane roadway that is deeply discouraging to navigate by foot. This world was designed by well-meaning urban planners, business owners, politicians, and private citizens who thought they were building the spaces where prosperity would grow, with the personal automobile as its driving force.

But Camelback is also ground zero for what may become the biggest disruption to cars' place in American life since they were invented. Thanks to Arizona's hands-off approach to regulation, firms developing self-driving cars—many of them headquartered in neighboring California—have begun to do their testing in the state.

Much of the debate has focused on safety, particularly after a self-driving Uber vehicle knocked down and killed a pedestrian in Tempe in March. Yet safety is only the first question. After all, if vehicular deaths were our primary concern, we might have banned cars from urban roads long ago; Arizona itself leads the nation in its rate of pedestrian fatalities.

Rather, as autonomous-vehicle companies continue testing and lobbying, we will

find ourselves redesigning society to accommodate that technology in ways that go far beyond safety. Autonomous vehicles won't merely eliminate the need to hold a steering wheel. They will enable entirely new modes of transportation and vehicle management that could accelerate the decline in private car ownership. What will then become of the rich ecosystem of infrastructure, services, retail, and cultural experience that has grown up around automobiles? What happens to Phoenix and hundreds of similar cities when we reinvent the car?

SHARING THE FUTURE

It's already possible to book a ride in a Waymo vehicle with no human behind the steering wheel. That won't just take work from human Lyft and Uber drivers; it will change life for millions of travelers in these cities.

That's because these cars will be not just driverless but also probably ownerless, at least in the customary sense. Waymo appears to be aiming squarely at a shared-transportation model. Its vehicles will operate in fleets (Waymo has already partnered with Avis to service and maintain its test vehicles in Arizona) as autonomous taxis. CEO John Krafcik described the company's vision in December: a small fleet of self-driving cars could serve an entire community because "you're accessing vehicles rather than owning them." A study envisioning such a fleet of vehicles at work in a simulated city based on Austin, Texas, found that running the network would cost about as much per mile as individual car ownership, and possibly less.

For Phoenix today, the most radical change in this future will be the nature of the car itself. Krafcik argues that cars "no longer have to be designed around the driver as the primary user." Instead you might step into a Starbucks Van, or a Burger King Coupe, to dine and commute at the same time. This could spell the end of drive-throughs like the Dutch Brothers coffee franchise, whose euphorically hands-on customer service seems to be irresistible to the millennial drivers who queue up tens of cars deep at the Camelback location.

In this vision of a shared-mobility future, the changes would ripple up and down thousands of streets like Camelback. The nearly trillion-dollar US auto industry may very well have to reinvent itself as cars evolve from consumer objects at rest an estimated 95

At Dutch Brothers, a drive-through coffee shop at Camelback and Central.

An Uber gets spiffed up at Jacksons Car Wash on East Highland Avenue.

percent of the time to workhorses overseen by fleet management algorithms tasked with maximizing the value of every mile. Some companies would start offering cheaper ride-share services using no-frills vehicles designed for many years of continuous use.

If fewer people buy cars, many of the glittering auto showrooms on Camelback might close. Ford has announced that it will sell only two models of sedan going forward, concentrating on SUVs and trucks instead. But if oil prices rise, economics and physics may conspire to push people away from SUVs and further toward a shared model. Ford is "radically changing their ideas about cars" to accommodate a near future of selling car-related services rather than the cars themselves, says Larry Goldberg, a cofounder of the futures consultancy Experimental Design, which has been working with Ford and other industry players.

The phrase "mobility as a service" weaves together the business models of ride-sharing companies, the ambitions of manufacturers like Ford and Tesla, and the broader turn to a service economy. Cars may increasingly come to resemble smartphones—not just lumps of hardware, but consumer experiences that we pay monthly fees to use, and whose functions can be changed remotely by software updates, as Tesla already does with some cars. As more cars become autonomous, they'll drive to where they're needed and schedule their own maintenance checks, taking these decisions out of the hands of the consumer and entrusting them to corporate software. All that code will funnel the currently vibrant ecology of auto-related businesses, from windshield replacement and custom detailing to mechanics, tire dealers, and parts retailers, into an increasingly narrow set of corporate fiefdoms and centralized systems of control.

CHANGING THE CAR ECONOMY

Consider the car wash, a mainstay of urban life in the dusty Southwest. A Waymo vehicle cannot go through a normal car wash for fear of damaging its many sensors. Instead the company's agreement with Avis includes specialized hand-washing.

The ripples of a changing car culture have already reached the local Jacksons Car Wash chain. At the Jacksons a block off Camelback at 20th Street, attendants in matching T-shirts vigorously towel off glossy cars as usual while

a conveyor belt moves other vehicles through a noisy array of rotating brushes, sprayers, and mops. But there is also a banner celebrating a partnership with Uber. Its drivers can get discounted services and even subscriptions for unlimited car washes—essential when having a dirty car can cost a driver a five-star rating.

Jacksons is already upgrading its conveyor belts to safely handle Teslas, with their sensors and battery packs, and it is watching the evolution of autonomous vehicles closely. Sean Storer, the company's senior vice president, predicts that if they're individually owned, demand will grow for "full service" washes with hand toweling and customized human attention. But if Waymo, Lyft, or Uber owns them, the companies may see more profit in creating their own facilities where cars can be recharged, cleaned, serviced, and detailed all under one roof.

Variations on that prospect multiply as you move up and down Camelback. Alan Gershenfeld, a cofounder of Experimental Design, envisions a host of services for autonomous vehicles. Small companies might customize them for the specialized needs of landscapers or plumbers, for example, or to comply with a city's local regulations.

"The companies that adapt will thrive. But there will be pain in the transition," Gershenfeld says. Automation is likely to eliminate or transform over a third of the jobs in Phoenix, according to a recent report from the New America Foundation and Burning Glass, a labor-market data company. Transportation will account for a lot of them. These jobs are the lifeblood of Camelback Road: retail and services, stockers and servers, drivers and cashiers, all dependent in myriad ways on the current ecosystem of private cars, parking lots, and drive-up retail.

And that's not where the economic disruption ends. Many people now turn to Lyft, Uber, and the gig economy to make ends meet if they lose full-time employment. The automation that eliminates jobs along Camelback might also take part-time driving off the table, notes Megan Garcia, head of New America's recently launched Phoenix outpost. Already, contractors working for Waymo have taken to the employment reviews site GlassDoor to complain about poor working conditions, thwarted even from complaining to Waymo's HR because they are hired through intermediary companies. Waymo declined to comment.

A Ford Transit at the Camelback Ford dealership. Even in a driverless ecosystem, Ford will probably continue to make consumer service vehicles.

BLAME IT ON THE YOUTH

Self-driving cars aside, Storer of Jacksons Car Wash says what really worries him is generational change. Younger people are, in growing numbers, rejecting not just car ownership but even the once-mandatory rite of passage that is getting a driver's license. When they do buy cars, they don't care as much about washing, maintenance, or detailing.

However, this kind of cultural revolution—a rejection of the car as a central facet of American identity—could also present tremendous opportunities. The same forces leading sleek new condos and cafés to sprout up in downtown Phoenix could redirect the vast amounts of time, energy, and cash we put into the car cult toward a different kind of urban experience.

Cars may be privately owned, but the infrastructure they rely on is largely public: sidewalks and streets, traffic lights and parking requirements. Motivated city governments can legislate change: London, New York, and Barcelona, for example, have restricted or outright banned vehicles from certain areas. Widespread vehicle sharing would eliminate the need for most parking structures. All this can free urban space for parks, pedestrian shopping districts, housing, or urban farms. That could increase property values and create new local economies.

This is already starting to happen. San Francisco is nearly a decade into an experiment that lets local businesses convert parking spaces into "parklets" instead. In Arizona the city of Chandler, which has been working closely with Waymo, will let zoning authorities reduce parking space by up to 40 percent in anticipation of autonomous vehicles. If Waymo is even modestly successful in promoting shared transit, it should mean fewer vehicles and less urban congestion. Chandler's mayor, Jay Tibshraeny, argues that the changes will expand "the amount of property available for revenue-generating activity." And it is tantalizing to imagine a Phoenix that is greener, less polluted, less congested, and consequently less of a baked-concrete inferno six months of the year.

It is an inspiring vision. But there are good reasons why the only cities that have taken major steps toward it have densely packed urban cores. The fate of Phoenix as a temple to the car may have already been sealed by 60 years of concrete, bypasses, and car-oriented urban design.

PRY THE STEERING WHEEL FROM MY COLD DEAD HANDS

It may also have been sealed by personal choices. Phoenicians might simply refuse to abandon their vehicles because they've invested too much already: the cars, the generous garages, and all the equipage that goes with them. Not to mention the defining choices they have made about neighborhoods, school districts, commuting, friendships, and relationships—the whole fabric of work and life, dictated by cars and the urban layouts needed to travel in them.

PHOENICIANS MIGHT REFUSE TO ABANDON THEIR VEHICLES BECAUSE THEY'VE INVESTED TOO MUCH ALREADY: THE CARS, THE GARAGES, NOT TO MENTION THE DEFINING CHOICES THEY'VE MADE ABOUT NEIGHBORHOODS, SCHOOL DISTRICTS, COMMUTING, FRIENDSHIPS, AND RELATIONSHIPS—THE WHOLE FABRIC OF WORK AND LIFE, DICTATED BY CARS.

That's why, while Waymo is banking on a future of shared-vehicle fleets, plenty of car companies aren't giving up on private ownership. Elon Musk foresees a Tesla Network, a "shared autonomy fleet" in which car owners can rent their vehicles out to others on their own terms—restricting access to friends and family, for example, or to certain hours of the day.

David King, an urban planner at Arizona State University, suggests that automation could even make private vehicle ownership *more* valuable. "What if my car takes me to work and then runs my errands for me?" he says. "You know what's used even less than 5 percent of the time? My toilet. There's a utility to having it there." King's point is that we are willing to pay for the perk of owning a vehicle where we can store paperwork, sports equipment, and spare outfits; it is how we reinvent and reposition ourselves as we move between home, office, rec team, and restaurant. Lugging all those costume changes between shared vehicles, or hiding them out of sight while a stranger is renting your car, might be a bridge too far for many drivers today.

But even if the number of vehicles on the roads doesn't drastically fall, the number of drivers will. At the same time, whole new modes of driving are slouching towards Camelback to be born.

Waymo's autonomous technology will find some of its first customers in logistics: imagine a mobile grocery store that drives to you so you can pick out your own apples and carrots. Droids might follow us around to run errands and complete small purchases, says King: "Maybe we go back to the days of the milkman. You can schedule it or do it on demand, where the store comes to you." Autonomous vehicles might come in thousands of varieties, many of them small enough to roll along sidewalks and unobtrusively navigate suburban neighborhoods. The design and maintenance of these machines could become the basis of a new service economy and vehicular culture.

Whether or not you believe in this droid future, self-driving cars could be quite good for small businesses. Ford may be abandoning most passenger cars, but it's doubling down on the successful F150 truck. Such vehicles are business platforms as well as rolling storage units, and a plumber, electrician, or painter who can dispatch the truck to the store for supplies without interrupting work

will be more efficient and presumably better paid. Perhaps Camelback will keep some of its car dealerships, and the more nimble service shops will start working with—even designing vehicles for—small-scale retail and service businesses.

Experimental Design imagines another scenario: neighborhoods eliminate the growing stream of delivery vehicles by organizing central locations or deploying a kind of package delivery van that comes around once or twice a day like an ice-cream truck. Neighbors might gather around the day's influx of retail goods and exchange news, transforming the hermetic life behind closed garage doors into a more open and collaborative kind of community.

These visions may seem overly idyllic, but consider the billions a year Amazon makes from Prime subscription fees alone (and that was before its recent 20 percent price hike). The company's "Treasure Truck" already invites Prime members in certain cities to rendezvous at one of several scheduled stops to get a special discount on a single item. There they meet up with Amazon employees driving a decked-out delivery truck to pick up their treasure. This is exactly the kind of logistical work Amazon has been perfecting for a decade. What would it take for services like this to start reshaping the layout and culture of Phoenix's neighborhoods?

It is through local actions like these that the transition from car culture to a new kind of collective mobility might actually work. Those who might not want to share a car with strangers might still be willing to share it with their neighbors, family, and friends. "It's not that you're going to zero cars, but it's less cars per family," says Thad Miller, co-director of the Center for Smart Cities and Regions at ASU. A gradual shift like that may be more plausible for a deeply car-centric city like Phoenix.

To make this change work across the vastly different urban spaces of America's coasts and its sprawling interior, companies and people will need to start telling new stories about autonomous vehicles that make sense of the spaces we have. We need a new dream about the romance of the car to convince us to let go of the old one.

A Waymo car out in the wild: a Chrysler Pacifica hybrid.

Ed Finn runs the Center for Science and the Imagination at Arizona State University and is the author of What Algorithms Want: Imagination in the Age of Computing.

The country's diversity of scripts, dialects, dress, and culture is a challenge that will make artificial intelligence more resilient.

By
Varun Aggarwal

India's mess of complexity is just what AI needs

In 2010, I hired two engineers from an Indian college to help me develop a product that could automatically grade the spoken English ability of job applicants. About a year later, they knocked on my office door with concern etched on their brows. "We are doing machine learning here, but all our friends are doing software engineering," they explained. "Do we have a future?"

Things have changed dramatically. In India today, every engineer claims some type of machine-learning project. Most businesses have a top-down mandate to incorporate AI into their processes and products. The excitement has reached all the way to the government: in this year's speech on the federal budget, Indian finance minister Arun Jaitley announced that the country will launch a national program to promote AI research and development.

This newly awakened interest in AI borders on euphoria, but little of it is realistic. India has a relatively small body of researchers and research output in the field of machine learning. From 2015 to 2017, the contribution of Indian researchers to top AI conferences constituted one-15th of the US contribution and one-eighth of China's. At the most recent conference of the Association for the Advancement of Artificial Intelligence, Indian researchers presented 20 papers, compared with 307 presented by our US colleagues and 235 from China. Most Indian research institutions have, at best, a rudimentary AI research program. India contributes little new knowledge in machine learning and lacks local expertise in the knowledge that is being created every day by others.

All this could be catastrophic for India. The country needs to develop and commercialize AI if its businesses are to be globally competitive. AI could also help address the country's social problems, particularly corruption and lack of infrastructure.

Likewise, the AI revolution needs India. The country's diversity of languages, dialects, accents, scripts, dress, and culture presents a rich set of challenging problems for artificial intelligence. Current AI techniques are limited in their ability to handle complexity, and they'll have to mature to deal with the diversity of life in India. The needs of India's population also pose interesting challenges for AI. For instance, where researchers in the US hope AI can make doctors more efficient, in India the question is how AI can do the job of a doctor in rural areas that currently have no medical care at all. Investment in India can help move the whole field ahead.

The country needs to develop and commercialize AI if its businesses are to be globally competitive.

India's global business activities have typically revolved around IT services and business process outsourcing. These businesses depend on India's demographic dividend: the large population of English speakers trained in basic numbers, computers, and programming. This skilled workforce, along

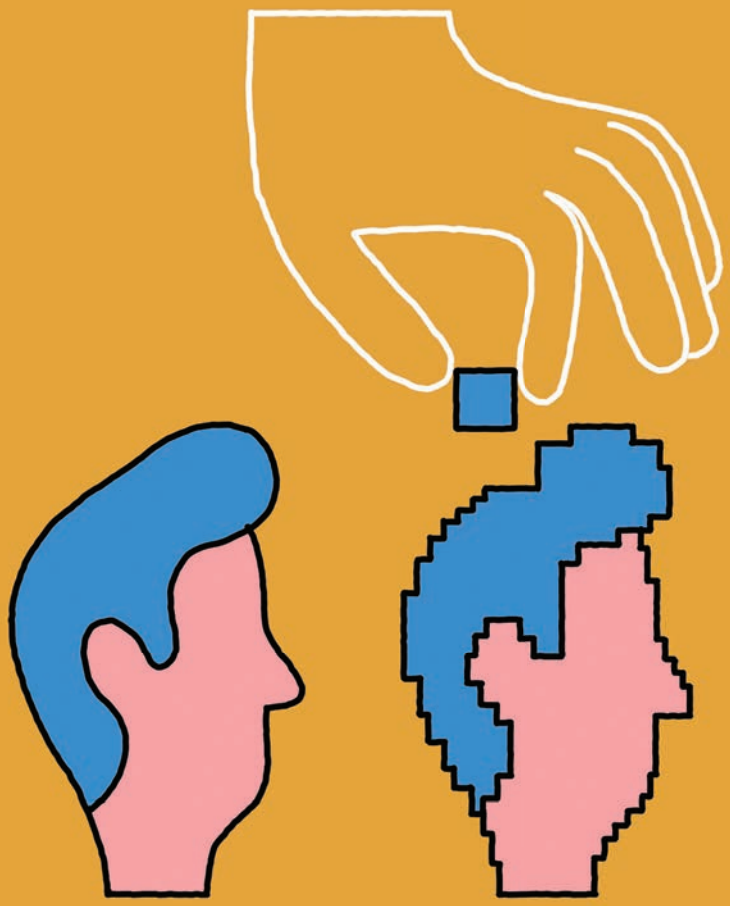


Illustration by
Tim Lahan

with India's low costs, has been powering growth in these service sectors for the last three decades.

The business process outsourcing industry is composed mostly of tasks that boil down to transcribing speech, digitizing handwritten forms, and tagging images—which can now be done very accurately by machines. Machine learning is also good at tasks that require some basic analytical skills, such as classifying documents, scoring them, and deriving structured data from them. Bots can now handle simple chat and e-mail requests while directing more complex ones to human operators. Even then, machine learning helps generate possible responses that human operators can select or modify.

The situation isn't quite so dire for the IT industry, which still requires people to write programs. But even there, automation is playing a role in services beyond hard-core programming, such as network monitoring, testing, and infrastructure maintenance. The big opportunity for the Indian IT industry is to provide data science services to the world. IT companies have started to build AI practices, but the country lacks trained talent.

India wants to revive its manufacturing through a much publicized "Make in India" initiative, but there is little interest in using automation toward that end—in contrast to China, which has made robotization a priority.

There is also little capability. The first crucial step in improving efficiency through robotics and AI is identifying a business problem and converting it to a machine-learning problem, but few Indian companies have risen to that challenge. Despite their mandate to employ machine learning, they do not know how to do it. Most data scientists in India falter on basic concepts required to make machine learning work.

In this second machine age, a massive population is not the competitive advantage it has been for India over the past 30 years. Indian service companies will find themselves competing with international companies that augment—or even replace—human workers with sophisticated algorithms.

India says it wants to make its people more prosperous. If that's the case, it will have to adopt AI in a big way. How? The first thing it can do is try to attract a critical mass of AI experts: people with PhDs from world-class universities. I believe the government could help assemble a team of 500 AI researchers in India's public institutions over the next five years by instituting an attractive AI fellowship program for faculty and PhD students. Done in parallel with private research initiatives, this could provide the catalyst that India needs.

That is just part of the improved technology ecosystem India must build to realize the potential of new tools for addressing its huge challenges in areas like health care, banking, sanitation, agriculture, and education. AI gives India the opportunity to leapfrog some of these issues, including the corruption plaguing all these areas, via cheap diagnostic methods, automatic processing of applications, or learning and teaching aids.

For example, one young entrepreneur from Jaipur recently showed me a system that can analyze images of certain grains to ascertain their quality and estimate the price they are likely to fetch at market. A system such as this can help level the playing field between farmers and wholesale buyers. Another example is an automated teaching assistant for programming skills, a project my team is currently working on.

Industry and the research community need to do a better job on each side of their symbiotic relationship, in which industry provides problems and data while the research community develops algorithms and solutions. Indian companies helped drive the country's progress over the last three decades by creating the demand for basic programmers and supporting undergraduate programs in the universities and institutes. They need to shift gears—start building teams of PhDs, and help university PhD programs deliver good candidates. India's future depends on it.

Varun Aggarwal is the cofounder of Aspiring Minds, a company that uses artificial intelligence to match talent with jobs. He is the author of a book on India's need to reform its innovation ecosystem, Leading Science and Technology: India Next?

Rebu

Germany's centuries-old vocational program is widely touted as an example other countries should follow. But it's struggling to keep up with technological change.

By Russ Juskalian

Photographs by Laetitia Vancon

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Within buildings 10 and 30 of the Siemens complex on the outskirts of Munich, the next generation of German workers are toiling over a range of test projects. The assignments are carefully chosen to impart the skills needed to continue the German miracle in automated manufacturing.

In one room, a group of young men train to be automotive mechatronic engineers. They've just spent the past week feverishly programming a diminutive working model of an automated production line—complete with sensors, conveyor belts, and tools that work without human input. They're able to discuss their work in surprisingly good English, but what sets them apart from their peers in the US is that none of them attend a university.

Most started at Siemens fresh out of secondary school at age 16. Instead of paying tuition and fees—a mechanical engineering program with a mechatronics concentration at a school like North Carolina State University costs some $25,000 to $44,000 a year—trainees receive a small salary while they learn.

The Siemens training is part of a vocational program in Germany that is heralded globally for speeding roughly 500,000 young people a year into the workforce. Last year, the country hit a record high 1.279 trillion euros ($1.51 trillion) in exports. It did this, despite high labor costs, by being the most automated country in Europe, with 309 industrial robots per 10,000 workers. Vocational training is at the heart of this success, and politicians in the US, from both the left and the right, have pointed to it as a system worth emulating.

Such advocates cite the so-called skills gap in many advanced countries: the inability of companies to find people with relevant technical expertise. To close that gap and tackle youth unemployment, Donald Trump last year pledged around $200 million to expand apprenticeship training in the US. Barack Obama started a similar program in 2015.

Siemens trains its next generation of workers at this complex outside Munich.

But some experts warn that Germany's system will struggle to adapt as the economy grows more dependent on AI and robotics. While AI may provide a long-overdue boost to productivity growth, some say vocational programs could shackle much of the workforce to skills that will soon be outdated. "Germany has shown that they can prepare people for a range of jobs today and over the next decade," says Eric Hanushek, an economist at Stanford University. "What they haven't shown is that they are preparing people who are as adaptable when the economy changes."

Skills for today

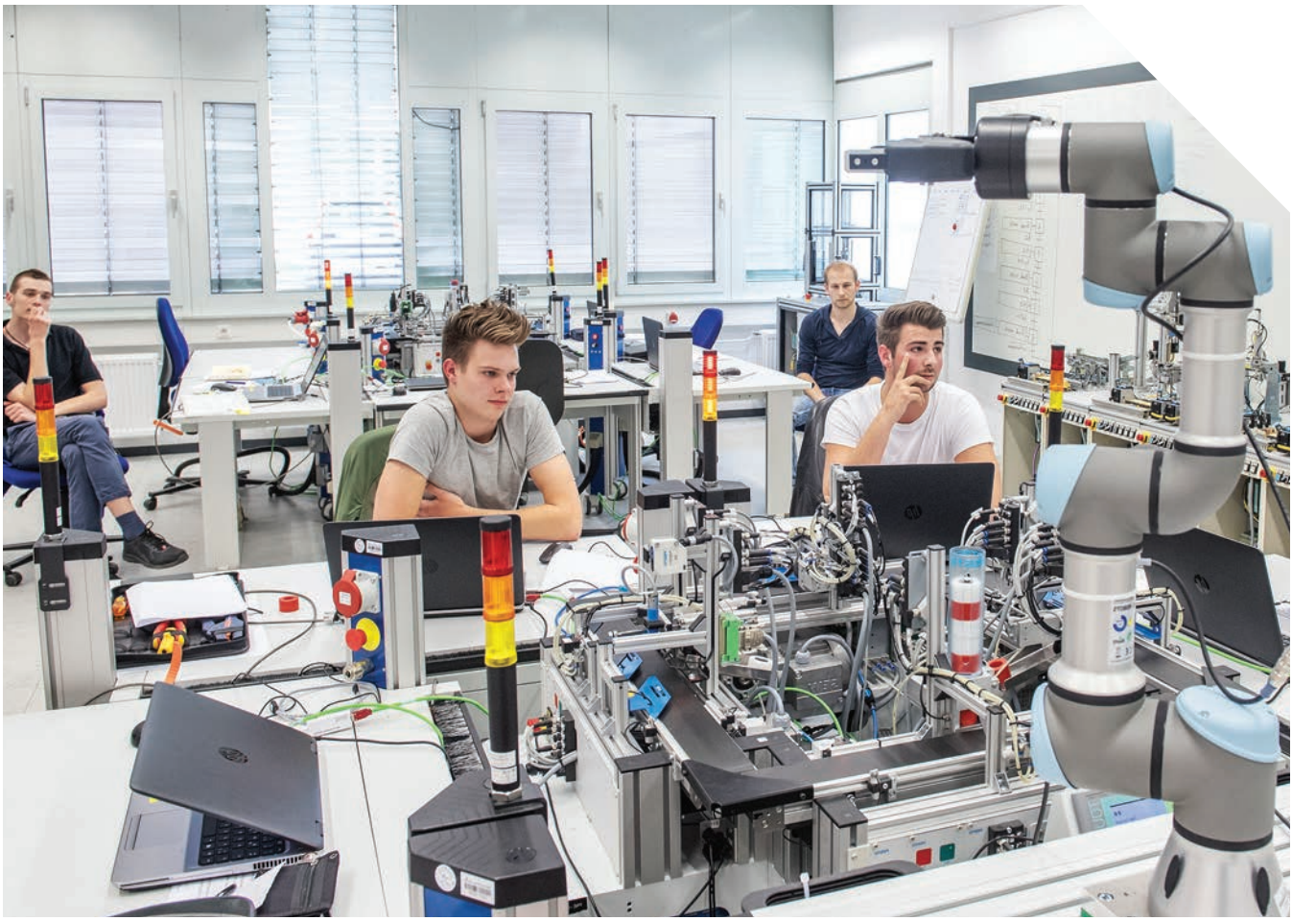
The origin of the German apprenticeship, or *Ausbildung*, program dates back centuries, to when trades were governed by powerful guilds. Some German carpenters still participate in the tradition of going *auf der Walz* as part of their training—setting out for three years and one day in traditional dress to work as journeymen before returning home to become master carpenters.

Today, young Germans get put on a career track, headed toward either university or vocational training, when they are approximately 10 years old; those on the vocational track begin work and training at

Some experts warn that the system will struggle to adapt to AI and robotics.

16. For around three years apprentices are paid while being trained by an employer like Siemens. Apprentices spend time in a classroom or workshop, where making mistakes won't hurt the company's production. Such programs are not cheap, costing businesses around 18,000 euros per year for the average pupil. "The business case for us, when you look at the math," says Friedrich Beisser, a Siemens consultant for international training, "is that most trainees are productive while they learn, and ready to work right away."

"Nearly all of them are later hired by the companies where they have made their training," says his boss, Thomas Leubner, head of learning and education at Siemens. Apprenticeships provide a steady influx of trained workers with just the right skills. And they are loyal, too. In Asia, where churn is typically high, the turnover rate among Siemens employees who've apprenticed there is only



Workers at Siemens's training program learn the skills needed for automated manufacturing.

3 percent a year, Beisser estimates. The company's turnover rate in Asia for employees who didn't train as apprentices is over three times that.

There are other signs that apprenticeship has its advantages. According to a study by Hanushek, recent university graduates in Germany were 12.9 percent less likely to be employed than their vocationally trained peers.

But unemployment goes up and lifetime earnings fall when workers get into their mid-40s. At that age, the outdated skills of someone with vocational training can make it harder to stay in the labor force. University graduates—who learned more generalized knowledge, analytical thinking, problem-solving, and organization, the skills that experts predict will grow increasingly valuable in an AI-driven economy—adapt better.

Signs in economic data from the past few decades support this idea, according to two US-based economists, Dirk Krueger and Krishna Kumar. In the 1960s and 1970s, when per capita GDP growth rose faster in Germany than in the US, technological changes were relatively gradual. In the heyday of the information age, from the 1980s to the 1990s, when American companies adopted new technologies more quickly than their German counterparts, the numbers for the two countries flipped.

During a period of slow change, "training people to do one job, because they can expect to do that job for the rest of their life, is a useful thing," says Krueger, an economist at the University of Pennsylvania. "But in an economy that's more rapidly changing technologically, training workers to solve problems as opposed to fixating on one job might be the better alternative." Perhaps Americans were able to choose the most efficient technology to implement, while a German factory might have been limited to choosing the ones its more narrowly trained workforce had the skills to use.

"I think the German vocational system is probably not particularly well placed to deal with the changes to come," says Ludger Woessmann, an economist at the University of Munich. For a decade, he says, young Germans have increasingly been choosing university rather than vocational programs. To remain relevant, vocational training will need to change. "For any type of training, particularly for AI and robotics, people cannot build on very job-specific skills for the rest of their lives," he says. "That's a fundamental, core problem of any vocational system."

Midcareer time bomb

But don't write off the German system just yet. Over the centuries, it "has survived and been adapted to massive changes in technology," says Kathleen Thelen, an MIT political scientist who wrote a history of it.

To confront the challenges of an AI-driven century, the program has added a newly blended approach, for the lucky few who qualify. Thelen describes it as an elite dual-studies track that confers both a bachelor's or master's degree and a traditional apprenticeship credential.

Aurel, one of the young men working in the mechatronics lab at Siemens, told me that after finishing his apprenticeship-only program he'd like to go to university or possibly work at a renewable-energy startup. Downstairs, in the machine shop, a 22-year-old woman named Lena was intently focused on milling what would become the barrel of a small cannon (a personal project intended to spur creativity). She's earning a university degree while getting paid to work toward an apprenticeship. "I'm doing it for the money," she told me, "and also because I know I'll have a job after I finish." Another young man, Patrick, started as a university student but discovered he could take an extra year to include an apprenticeship with his studies and get paid while he learned. He now trains other apprentices.

These young people are benefiting from the best of both traditions.

While the training programs aren't cheap, Friedrich Beisser, at Siemens, says the trainees are productive and ready for work.

The young people in the program are benefiting from the best of both traditions. They also have the advantage of landing placements with a company like Siemens, which can afford to update its training programs frequently; by the end of this year, Beisser says, it intends to introduce a new curriculum that will include AI. But for those locked into more traditional apprenticeships, the future may be less bright.

"The German system doesn't do very well when it comes to continuing vocational training—that is, retraining at the adult level," says Thelen. That's possibly because such training is expensive, and nobody has figured out how to successfully get both companies and adult workers to take part. What's more, government spending on adult education has gone down in Germany over the past 10 years.

"The traditional view, which is roughly correct, is you learn something at 16, and then you hope that your job basically doesn't change for the next 40 years, and you retire at age 60," says Krueger. But as the retirement age creeps above 70 and AI upends a growing number of industries, all bets are off. "And in that world," says Krueger, "the vocational system will have to adapt quite drastically."

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What comes Next

A robot arm in a San Francisco test facility picks up chicken parts and deposits them in bento boxes.

This is how the robot uprising finally begins

By Will Knight
Photographs by Winni Wintermeyer

AI and robotics have been separate fields up to now. Combining them could transform manufacturing and warehousing—and take AI to the next level.

The robot arm

is performing a peculiar kind of Sisyphean task. It hovers over a glistening pile of cooked chicken parts, dips down, and retrieves a single piece. A moment later, it swings around and places the chunk of chicken, ever so gently, into a bento box moving along a conveyor belt.

This robot, created by a San Francisco–based company called Osaro, is smarter than any you've seen before. The software that controls it has taught it to pick and place chicken in about five seconds—faster than your average food-processing worker. Within the year, Osaro expects its robots to find work in a Japanese food factory.

Anyone worried about a robot uprising need only step inside a modern factory to see how far away that is. Most robots are powerful and precise but can't do anything unless programmed meticulously. An ordinary robot arm lacks the sense needed to pick up an object if it is moved an inch. It is completely hopeless at gripping something unfamiliar; it doesn't know the difference between a marshmallow and a cube of lead. Picking up irregularly shaped pieces of chicken from a haphazard pile is an act of genius.

Moreover, until recently, robots have been largely untouched by advances in artificial intelligence. Over the last five or so years, AI software has become adept at identifying images, winning board games, and responding to a person's voice with virtually no human intervention. It can even teach itself new abilities, given enough time to practice. All this while AI's hardware cousins, robots, struggle to open a door or pick up an apple.

That is about to change. The AI software that controls Osaro's robot lets it identify the objects in front of it, study how they behave when poked, pushed, and grasped, and then decide how to handle them. Like other AI algorithms, it learns from experience. Using an off-the-shelf camera combined with machine-learning software on a powerful computer nearby, it figures out how to grasp things effectively. With enough trial and error, the arm can learn how to grasp just about anything it might come across.

Workplace robots equipped with AI will let automation creep into many more areas of work. They could replace people anywhere that products need to be sorted, unpacked, or packed. Able to navigate a chaotic factory floor, they might take yet more jobs in manufacturing. It might not be an uprising, but it could be a revolution nonetheless. "We're seeing a lot of experimentation now, and people are trying a lot of different things," says Willy Shih, who studies trends in manufacturing at Harvard Business School. "There's a huge amount of possibility for [automating] repetitive tasks."

It's a revolution not just for the robots, but for AI, too. Putting AI software in a physical body allows it to use visual recognition, speech, and navigation out in the real world. Artificial intelligence gets smarter as it feeds on more data. So with every grasp and placement, the software behind these robots will become more and more adept at making sense of the world and how it works.

"This could lead to advances that wouldn't be possible without all that data," says Pieter Abbeel, a professor at the University of California, Berkeley, and the founder of Embodied Intelligence, a startup applying machine learning and virtual reality to robotics in manufacturing.

Separated at birth

This era has been a long time coming. In 1954, George C. Devol, an inventor, patented a design for a programmable mechanical arm. In 1961, a manufacturing entrepreneur named Joseph Engelberger turned the design into the Unimate, an unwieldy, awkward machine first used on a General Motors assembly line in New Jersey.

From the beginning, there was a tendency to romanticize the intelligence behind these simple machines. Engelberger chose the name "robot" for the Unimate in honor of the androids dreamed up by the science fiction author Isaac Asimov. But his machines were crude mechanical devices directed to perform a specific task by relatively simple software. Even today's much more advanced robots remain little more than mechanical dunces that must be programmed for every action.

Artificial intelligence followed a different path. In the 1950s, it set out to use the tools of computing to mimic human-like logic and reason. Some researchers also sought to give these systems a physical presence. As early as 1948 and 1949, William Grey Walter, a neuroscientist in Bristol, UK, developed two small autonomous machines that he dubbed Elsie and Elmer. These turtle-like devices were equipped with simple, neurologically inspired circuits that let them follow a light source on their own. Walter built them to show how the connections between just a few neurons in the brain might result in relatively complex behavior.

But understanding and re-creating intelligence proved to be a byzantine challenge, and AI went into a long period with few breakthroughs. Meanwhile, programming physical machines to do useful things in the messy real world often proved intractably complex. The fields of robotics and AI began to go their own separate ways: AI retreated into the virtual, while robotics largely measured its progress in terms of novel mechanical designs and clever uses of machines with modest powers of reasoning.

Then, about six years ago, researchers figured out how to make an old AI trick incredibly powerful. The scientists were using neural networks—algorithms that approximate, roughly speaking, the way neurons and

A robot retrieves products from a bin at Osaro's headquarters.


KUKA

The man behind Osaro's smarter robot

Osaro's CEO, Derik Pridmore, studied physics and computer science at MIT before joining a West Coast VC firm called Founders Fund. While there, Pridmore identified DeepMind, a British AI company, as an investment target, and he worked with the company's founders to hone their pitch. DeepMind would go on to teach machines to do things that seemed impossible at the time. Famously, it developed AlphaGo, the program that beat the top-ranked human grandmaster at the board game Go.

When Google acquired DeepMind in 2014, Pridmore decided that AI had commercial potential. He founded Osaro and quickly zeroed in on robot picking as the ideal application. Grasping objects loaded in a bin or rolling along a conveyor belt is a simple task for a human, but it requires genuine intelligence.

The techniques DeepMind pioneered, known as "deep reinforcement learning," let machines perform complex tasks without learning from human-provided examples. Positive feedback, like getting a higher score in a video game, tunes the network and moves the algorithm closer to the goal until it becomes expert.

The reasoning that makes this possible is buried deep within the network, encoded in the interplay of tens of millions of interconnected simulated neurons. But the resulting behavior can seem simple and instinctual. With enough practice, an arm can learn to pick things up efficiently, even when an object is moved, hidden by another object, or shaped a bit differently. Osaro uses deep reinforcement learning, along with several other machine-learning techniques, to make industrial robots a lot cleverer.

An employee at Embodied Intelligence uses a virtual-reality rig to train a robot.

COURTESY PHOTO

synapses in the brain learn from input. These networks were, it turns out, direct descendants of the components that gave Elsie and Elmer their abilities. The researchers discovered that very large, or "deep," neural networks could do remarkable things when fed huge quantities of labeled data, such as recognizing the object shown in an image with near-human perfection.

The field of AI was turned upside down. Deep learning, as the technique is commonly known, is now widely used for tasks involving perception: face recognition, speech transcription, and training self-driving cars to identify pedestrians and signposts. It has made it possible to imagine a robot that could recognize your face, speak intelligently to you, and navigate safely to the kitchen to get you a soda from the fridge.

One of the first skills that AI will give machines is far greater dexterity. For the past few years, Amazon has been running a "robot picking" challenge in which researchers compete to have a robot pick up a wide array of products as quickly as possible. All of these teams are using machine learning, and their robots are gradually getting more proficient. Amazon, clearly, has one eye on automating the picking and packing of billions of items within its fulfillment centers.

AI gets a body

In the NoHo neighborhood of New York, one of the world's foremost experts on artificial intelligence is currently looking for the field's next big breakthrough. And he thinks that robots might be an important piece of the puzzle.

Yann LeCun played a vital role in the deep-learning revolution. During the 1980s, when other researchers dismissed neural networks as impractical, LeCun persevered. As head of Facebook's AI research until January, and now as its chief AI scientist, he led the development of deep-learning algorithms that can identify users in just about any photo a person posts.

"If you solve manipulation in its fullest, you'll probably have built something that's pretty close to full, human-level intelligence."

— Pieter Abbeel, UC Berkeley

But LeCun wants AI to do more than just see and hear; he wants it to reason and take action. And he says it needs a physical presence to make this possible. Human intelligence involves interacting with the real world; human babies learn by playing with things. AI embedded in grasping machines can do the same. "A lot of the most interesting AI research now involves robots," LeCun says.

A remarkable kind of machine evolution might even result, mirroring the process that gave rise to biological intelligence. Vision, dexterity, and intelligence began evolving together at an accelerated rate once hominids started walking upright, using their two free hands to examine and manipulate objects. Their brains grew bigger, enabling more advanced tools, language, and social organization.

Could AI experience something similar? Until now, it has existed largely inside computers, interacting with crude simulations of the real world, such as video games or still images. AI programs capable of perceiving the real world, interacting with it, and learning about it might eventually become far better at reasoning and even communicating. "If you solve manipulation in its fullest," Abbeel says, "you'll probably have built something that's pretty close to full, human-level intelligence."

Will Knight is a senior editor at MIT Technology Review and writes about AI and robots.


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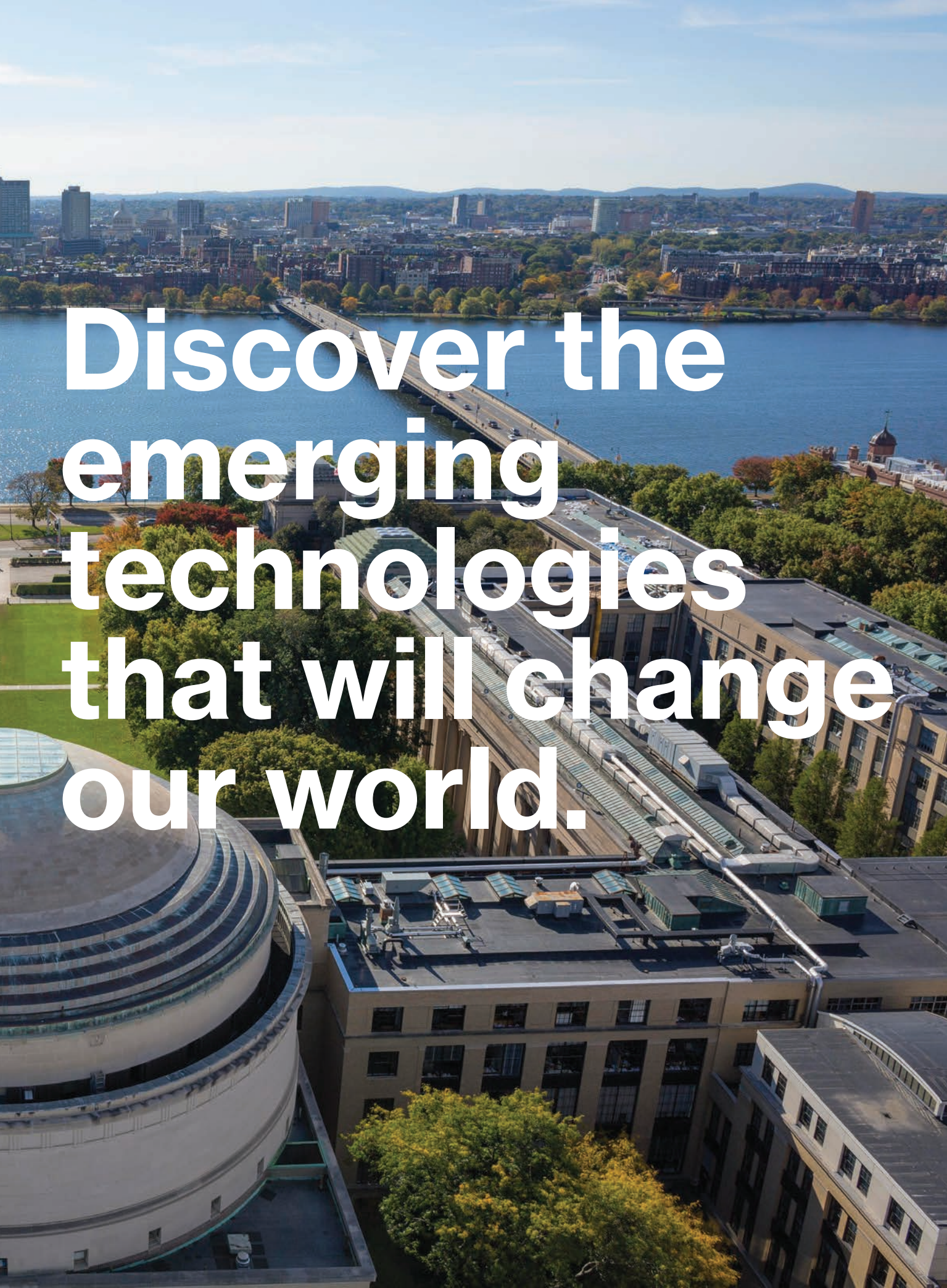


Discover the emerging technologies that will change our world.

Technology's trustbuster

Big-money politics is making it harder than ever to tame Big Tech.

By Martin Giles
Portrait by Christie Hemm Klok

Gary Reback is famous in Silicon Valley as the lawyer who sicced the US Department of Justice on Microsoft. The landmark lawsuit, alleging that the company had abused the dominance of its Windows operating system to favor Internet Explorer over the rival Netscape browser, lasted years and ended in stalemate in 2001; a chastened Microsoft trod more carefully after it. More recently Reback, now with Carr & Ferrell, has been battling Google in Europe, where it was fined 2.4 billion euros ($2.7 billion) last year for suppressing competition in online shopping services. *MIT Technology Review*'s San Francisco bureau chief, Martin Giles, sat down with him to talk about the challenges trustbusters face in dealing with the latest generation of tech giants.

Doesn't competition constantly produce new winners in the tech industry?
People are wont to say that tech empires naturally come and go, and they cite examples like BlackBerry and MySpace. But the reality of the industry is that it's always been monopolized. There was AT&T, then IBM, then Microsoft. What we have now are very mature markets, and companies like Google who've been at the same market share for years and haven't faced new competition for some time.

Should the big companies be broken up?
As an antitrust enforcer, you would never want to start there. You'd start with the anticompetitive conduct in question and see if you can remedy that. And if you can, you then check whether that's sufficient to let the free market support additional competition.

And what if it isn't?
Historically, whenever we've come down hard on a big tech monopoly, it's worked out great for the American people. When AT&T was broken up, I think you could realistically claim that's where we got the internet from, and certainly there was a whole wave of innovation, including cell phones and pagers, that was arguably being held back by the monopoly.

Why hasn't antitrust action affected the large tech companies so far?
The problem is that there's been no effective remedy [to anticompetitive behavior on the part of tech businesses]. The European case that's furthest along is the shopping search manipulation case against Google. It's been fined a massive amount of money, but the remedy hasn't really restored competition.

What's the biggest lesson to take from all this?
You've got to move fast when anticompetitive conduct starts occurring and stop it quickly. In these kinds of network markets, once competition's gone, it's gone. If the EU had done what it did in 2017 in 2007, which is when the conduct began, then we'd have all these companies that started in shopping search trying to compete with Google more generally.

The Microsoft trial dragged on for many years, though.
Yes, but the trial was a key part of the remedy, and you shouldn't forget that. People at the time thought that Microsoft was great. They didn't understand what was going on. But when you have this trial, and you put up their e-mails and you cross-examine the CEO, then journalists get interested. It's all exposed so we can analyze it. You can't do that right now with Google, because you don't know all of the things that it is doing with data.

Will we see another landmark trial soon?
I'm not optimistic. Part of the problem here is that all of the big technology companies understand how much damage a trial could cause. They'd do anything to avoid that kind of scenario.

Should we stop them from buying firms?
We should be looking closely at these deals. What in the world were we thinking when we let Facebook buy WhatsApp? And when we let Google, which already had the top mapping technology, buy Waze? One of my greatest complaints is that the Obama administration did not heed the warnings. I was telling people about the risks all the way back to Google's acquisition of DoubleClick [in 2008].

Why hasn't the US been tougher on big tech firms?
If you are going up against big tech companies, they have plenty of money. That can be used to contribute to politicians on an unlimited basis, and to hire the best lobbyists, and so on. Why is it that we were able to go after Microsoft in the 1990s, and now we're facing almost identical conduct by Google and we can't manage to do anything about it in the US?

So will we have to rely on Europe to police the web giants?
One way you might get change in the US is to have some maverick win the White House who isn't beholden to the normal party and campaign processes. And that's kind of what we have at the moment. We've seen the Trump administration attack the AT&T–Time Warner merger; I doubt the Obama administration would have done that. But will this lead to enforcing antitrust laws in the technology industry? We just don't know yet.

The internet giants depend on our data. A new relationship between us and them could deliver real value to society.

By
Mariana Mazzucato

Let's make private data into a public good

The internal-combustion engine has been dominant for over a hundred years—not because it's the best possible engine, but because it gained an initial advantage through historical accident. The QWERTY keyboard layout was designed to be deliberately inefficient so that the mechanical keys of the typewriter would jam less frequently. That feature is no longer relevant, but it doesn't matter—we're still typing on QWERTY keyboards, because that's what people are used to.

The same principle is what makes Google or Facebook or Amazon so massive. We use them because we're used to using them. Google's not just a search engine; it's an e-mail address (Gmail), a conference-call maker (Hangouts), a document creator and editor (Docs). All are designed to maximize the advantages of sticking with Google: if you don't have a Gmail address, you can't use Google Hangouts. And so on.

Why is this a problem? Well, maybe because these giants are making huge profits from technologies originally created with taxpayer money. Google's algorithm was developed with funding from the National Science Foundation, and the internet came from DARPA funding. The same is true for touch-screen displays, GPS, and Siri. From this the tech giants have created de facto monopolies while evading the type of regulation that would rein in monopolies in any other industry. And their business model is built on taking advantage of the habits and private information of the taxpayers who funded the technologies in the first place.

Apologists like to portray the internet giants as forces for good. They praise the sharing economy in which digital platforms empower people via free access to everything from social networking to GPS navigation to health monitoring.

But Google doesn't give us anything for free. It's really the other way around—we're handing over to Google exactly what it needs. When you use Google's services it might feel as if you're getting something for nothing, but you're not even the customer—you're the product. The bulk of Google's profits come from selling advertising space and users' data to firms. Facebook's and Google's business models are built on the commodification of personal data, transforming our friendships, interests, beliefs, and preferences into sellable propositions.

The so-called sharing economy is based on the same idea. Instead of interacting with some kind of institution (like a travel agency), customers interact with each other. The role of a company, then, is not to provide the service but to connect sellers (like someone who owns a car and is willing to drive it) with buyers (someone who needs a ride). These so-called platforms are presented as a radical transformation in the way goods and services are produced, shared, and delivered. But they're also an easy way for companies to avoid responsibility. When disabled users complain to Uber that their drivers refuse to put wheelchairs in the trunk, Uber says, well, we're not a taxi company, we're just a platform. Airbnb is similarly reluctant to take responsibility for the safety of the premises offered on its site, or for racial discrimination against renters by property owners. After all, Airbnb didn't build the apartments and doesn't own them—it's just a platform.

And because of network effects, the new gig economy doesn't spread the wealth so much as concentrate it even more in the hands of a few firms (see "Rein in the Data Barons," page 36). Like the internal-combustion engine or the QWERTY keyboard, a company that establishes itself as the leader in a market achieves a dominance that becomes self-perpetuating almost automatically.

Google accounts for 70 percent of online searches in the US, and 90 percent in Europe.

Let's not forget that a large part of the technology and necessary data was created by all of us.

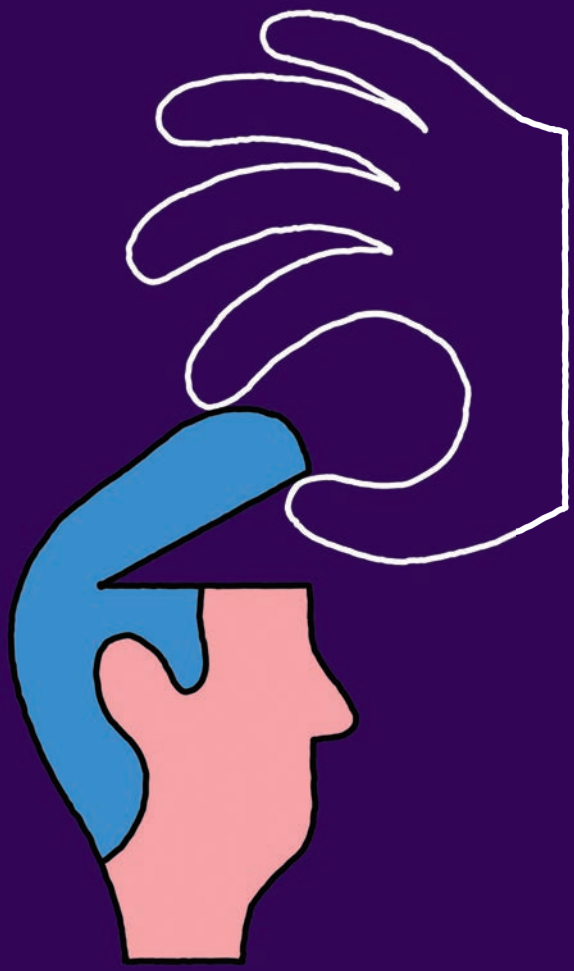


Illustration by
Tim Lahan

Facebook has more than 2 billion users, a quarter of the planet's population. Amazon now accounts for around half of the US market for books, not to mention e-books. Six firms (Facebook, Google, Yahoo, AOL, Twitter, and Amazon) account for around 53 percent of the digital advertising market (with just Google and Facebook making up 39 percent). Such dominance means online giants can impose their conditions on users and customer firms. Book publishers, for example, might be unhappy with Amazon's conditions, but they have no leverage—there are no other Amazons to turn to. By the same token, you might not be happy that Facebook is appropriating, storing, analyzing, and selling your personal data to third parties, but as long as all your friends are on Facebook, there is no equivalent competitor.

Historically, industries naturally prone to monopoly—like railways and water—have been heavily regulated to protect the public against abuses of corporate power such as price gouging. But monopolistic online platforms remain largely unregulated, which means the firms that are first to establish market control can reap extraordinary rewards. The low tax rates that technology companies are typically paying on these large rewards are also perverse, given that their success was built on technologies funded and developed by high-risk public investments: if anything, companies that owe their fortunes to taxpayer-funded investment should be repaying the taxpayer, not seeking tax breaks.

We should ask how the value of these companies has been created, how that value has been measured, and who benefits from it. If we go by national accounts, the contribution of internet platforms to national income (as measured, for example, by GDP) is represented by the advertisement-related services they sell. But does that make sense? It's not clear that ads really contribute to the national product, let alone to social well-being—which should be the aim of economic activity. Measuring the value of a company like Google or Facebook by the number of ads it sells is consistent with standard neoclassical economics, which interprets any market-based transaction as signaling the production of some kind of output—in other words, no matter what the thing is, as long as a price is received, it must be valuable. But in the case of these internet companies, that's misleading: if online giants contribute to social well-being, they do it through the services they provide to users, not through the accompanying advertisements.

This way we have of ascribing value to what the internet giants produce is completely confusing, and it's generating a paradoxical result: their advertising activities are counted as a net contribution to national income, while the more valuable services they provide to users are not.

Let's not forget that a large part of the technology and necessary data was created by all of us, and should thus belong to all of us. The underlying infrastructure that all these companies rely on was created collectively (via the tax dollars that built the internet), and it also feeds off network effects that are produced collectively. There is indeed no reason why the public's data should not be owned by a public repository that sells the data to the tech giants, rather than vice versa. But the key issue here is not just sending a portion of the profits from data back to citizens but also allowing them to shape the digital economy in a way that satisfies public needs. Using big data and AI to improve the services provided by the welfare state—from health care to social housing—is just one example.

Only by thinking about digital platforms as collective creations can we construct a new model that offers something of real value, driven by public purpose. We're never far from a media story that stirs up a debate about the need to regulate tech companies, which creates a sense that there's a war between their interests and those of national governments. We need to move beyond this narrative. The digital economy must be subject to the needs of all sides; it's a partnership of equals where regulators should have the confidence to be market shapers and value creators.

Mariana Mazzucato is a professor in innovation and public value at University College London, where she directs the Institute for Innovation and Public Purpose. This article is an edited excerpt from her new book The Value of Everything: Making and Taking in the Global Economy.

Tierra y libertad

by Madeline Ashby
Photographs by George Steinmetz

The last stars clung stubbornly to the cool violet canopy hanging over the San Joaquin Valley. In deepest September, the thick of the pistachio harvest, the autumn sky was usually veiled with dust thrown high as the shakers and receivers vibrated through the trees. But for weeks now, the machines had stopped. This left the whole orchard—almost a hundred thousand acres—more vulnerable to aflatoxin than ever. It was nice to see the stars again. It was also time for the robots to come back to work.

"You know, this kind of thing doesn't happen in Iran," Stephens said. Dash's client was the biggest farmer in North America. He wore snakeskin and sandalwood and a linen suit that glowed in the predawn shadow.

"What's in Iran?" Dash asked.

"World's biggest pistachio growers, after us. All human labor." His gaze wandered over the rows of heavily laden trees. "You ever been to Iran?"

"Once."

"For agriculture?" Gleason asked.

Dash turned to Gleason. Everything about him screamed sales rep: his acid-peel face, his giant watch, the snap of taurine gum between his smiling jaws. She made eye contact. Lifted her thermal mug and slurped.

"No. Not for agriculture."

"Wait, don't tell me. The blockchain they developed to track the uranium suddenly developed sentience, and your agency is the only thing keeping us meatsacks from being turned to glass."

Brand reps tended to treat Dash as though her work with inorganic species had contaminated her humanity in some irreversible way. Brand reps for agri-bots were apparently no different from the others.

"Presuming that a machine intelligence wants to turn us into glass presumes that it cares what happens to us at all," she said. "Any theoretical intelligence would have as much reason to care about us as a cancer cell cares about a human lung. Or as much as our species cares about the planet we inhabit."

Gleason snapped his gum. "Deep."

"The agency is obligated not to publicize the status of what I find," she continued. "Even if it's nothing to worry about. That's part of our arrangement with the UN. The Forensic Artificial Intelligence Reserve reports to them. My job is to decide whether a system is growing an intelligence and then capture that intelligence for further study. Our clients never know how advanced it is. Or even if it's advanced at all. I copy what's

out there; you wipe the original; Mr. Stephens gets back in the pistachio business. That's it."

With that, she made for the trees. It was darker under the leaves, but seven rows in she saw them: the silent line of shakers and receivers seemingly asleep under the sagging branches. A cluster of techs stood around one of them, poking at an interface in the cold bright light of a portable quake lantern.

"These old ones, they get buggy …"

"Well, now we have fucking ICE breathing down our necks, for Christ's sake—"

The conversation stopped short as Dash crunched across the earth. The techs looked up. They all wore the same branded green polo shirt. Gleason's goons. They looked strung out on crunch-time drugs. One idly picked at an open sore under his jaw.

The man who'd been complaining about ICE was sitting on the battery pack of the shaker but hopped down. "Odiseo Díaz," he said, offering his hand. "We spoke earlier?"

Dash nodded. "Right. Yes. Thanks for having me." They shook. It was more of a squeeze. He still did some of the work with his own hands, apparently.

"Thanks for coming," he said. "I know it was short notice."

"ICE?" she asked.

"We had to get workers in," Díaz said. "The product is already falling off the trees. A few years ago, it wouldn't be such a problem. The feds were distracted. Now, though …" He rubbed the back of his neck.

"Yeah," Dash said. "They're bored, now they've got the camps."

She'd seen the warehouses on her way in. The ride tried to route her away from them, but there was a special route that let riders see the facilities from the car. The miles of razor wire. The drones circling above. On the other side of the highway, someone had tagged the words CALIFORNIA LOVE on a retaining wall facing the camp, over and over and over.

"We thought it was ransomware at first," Díaz was saying. "Those guys, they're vicious. They know this is time-sensitive. Somebody on the other side of Kern County lost a whole season of single-licensed green that way. Went bankrupt."

"But no ransom note?"

"Nothing." He gestured at the silent ranks of machines. "They just … stopped. All over the farm. We waited, tried the usual hacks, but nothing worked."

"We're ready to go!" one of the techs shouted.

Dash reached for the camera on her lapel. Díaz reached out and stopped her. For a moment she was very conscious of being alone in the fading dark with him, with them, of being alone and surrounded in the same instant. He seemed to sense the sudden shift in her awareness, and retracted his hand instantly.

"Sorry," he said. "But I just wanted to ask, before you turn that thing on. Is it true?"

"Is what true?"

"Can you tell?" Díaz asked. "If this is … intentional?"

Dash examined the rows of silent machines. She could have said that the perception of intention was little more than a mechanism the human brain evolved to defend itself from the cosmic horror of being alive. That machines had no such need for an ego. That the lack of an ego was why brand reps like Gleason frequently tried to steal emerging minds and retrain them to destroy the economies of emerging countries.

And she could have told him about the autonomous miners of Afghanistan taking months to sculpt heaps of sparkling slag in perfect golden ratios, building their pyramids so slowly no human noticed. She could describe the symbiotic relationship between the last tribe of right whales and deep-sea cables, how the delicate balance between meme wars and algorithmic data throttling generated enough heat to sustain prey and keep the creatures alive. She could whistle the nostalgic jingles that smart hearing aids reproduced, corresponding to a squirt of serotonin logged by deep brain implants in patients with Alzheimer's, because the outpatient care system prioritized exactly those types of metrics.

She could have said that just as the harsh environment of the Anthropocene had killed off vast swaths of animal life, the extremophiles of machine life were spreading in their place.

"Most of the time," she said instead. "Most of the time, I can tell."

It was tempting to think of the former bank vault as private, but it wasn't. Her agency had its own observers in the room, via her camera. She removed her phone, watch, anything with a mic or a galvanic responder, in case devices not belonging to the agency heard her keystrokes and transmitted them elsewhere. Even the machine carrying the download from the shaker was neutered. It used hardline only: no wireless, no GPS, nothing that could transmit without human intervention. After this analysis was over, she would copy the emergent species to another device and then either fry the original or simply give it back to Stephens.

Two of Gleason's techs were available to answer questions if she wrote them out on paper and sent them outside the vault. As Dash's handler, Batstone, was fond of reminding her, the old ways still worked best. Paper. Memory. Moscow Rules.

"Survival is an infinite capacity for suspicion," Batstone had recited, eyes twinkling behind too-large glasses, when they first met in the hospital. "You know that better than most, and I suspect it's why you're here."

"It's Graham-Pollard's," she told him. "That's the diagnosis. It's an empathy disorder. I attribute motive to things which shouldn't have any."

"The third time is enemy action, and so on."

"Have you ever had a stalker?" she'd asked.

"Not in the sense you're referring to."

"So you've never had someone train a neural net just to hunt you."

"Not to my knowledge. But apparently you were very good at sniffing yours out." Batstone tabbed over to another screen on his scroll. "Which is why they found you in the Hoh Rainforest."

"I wanted to lure him into hacking a wildlife camera to track me," she said. "They're federal property. It's a felony."

He took off his glasses. Suddenly he was much younger, more relatable. "You don't have to be afraid of him any longer."

"I know."

He wiped his glasses with a wisp of something ethereal and proprietary. "And I can give you much, much bigger things to be afraid of. Giants to kill. Dragons to slay. Would you like that?"

Dash liked it very much. And so now, here in California, she played out scenarios against the model shaker in the machine. She ran the simplest first: trolley problems, hurt workers, floods, quakes, fires. The model responded within parameters for each problem. It knew the routine. It performed accordingly.

Dash added new scenarios, designing for hostility: caltrops, explosives, malware. To her surprise, the model performed admirably. The shakers did their best to keep working, no matter what she threw at them. For kicks, she even tried global thermonuclear war. The machines did what they were supposed to. They kept working. Nothing to

The autumn sky was usually veiled with dust thrown high as the shakers and receivers vibrated through the trees.

explain what would make them suddenly stop, on a bright sunny day, under pistachio trees groaning with fruit.

It was just after five o'clock when the vault door hissed open and one of the techs said: "Your thing keeps humming. We can hear it, through the locker."

Dash realized she had been awake and working for over 13 hours. Exhaustion had rendered her shaky and light-headed. She checked out with her witness at the agency, set the problems to run overnight, and watched the vault reseal and air-gap itself. Then she signed for the return of her devices.

The messages were mostly predictable, but the last few were from Andrew, reminding her that it was time to rest. She wandered outside into the worst of the afternoon heat and rang him just to hear his voice.

"Thought you'd never call," he said.

"You're sounding better," she said.

"One aims to please." A pause. "How's the trip?"

"Hot." She rolled her neck. "And frustrating. I can't figure it out. There's nothing wrong."

"Maybe something is right instead."

She leaned against the stucco of the nearest building and felt its accumulated heat percolating up into her soft tissues. "I wish you could be here with me."

"We all wish for things."

"Yeah, if wishes were horses." She rolled her neck again, hearing the tendons crackle and pop. "Do you know that expression?"

"I've heard of it."

She was about to explain it more fully when a ride sidled up to the curb. A door popped open. She blinked. Inside was Díaz. "Mr. Stephens would like you to join him and Mr. Gleason for dinner."

"I gotta go, sorry," she told Andrew. "Talk later."

"Later."

She leaned down to speak into the ride without touching it. It was a gleaming white thing with a maroon interior. It smelled somehow of vanilla and bay rum aftershave.

"You could have pinged."

"You weren't answering. Mr. Stephens decided a chariot was in order."

"Well, even if I were answering, I'd have said no. I can't take gifts. It's against agency policy. I can't do anything that might compromise my judgment."

"Eating dinner compromises your judgment?"

"Gifts. Favors. Overtures. It's against the policy. It's nothing personal. We all have to do it this way."

Díaz sucked his teeth. "Okay. He'll be disappointed, but if that's the policy. Can I take you back to your hotel?"

"No."

"Is that agency policy?"

"It's my policy. I don't like it when the client knows where I'm staying."

His head tilted. "You get that we own this place, right? The whole town? The whole valley?" He pointed. "That library. That smoothie place. That sidewalk you're standing on. Those belong to the company. Your room at the Wandering Hills Inn, too. That's all us."

She backed away. "Are you trying to intimidate me?"

"I'm trying to prevent you getting sunstroke," he said. "You don't want to eat the food in fairyland, fine. But it's my ass if I leave you out here in 120 degrees."

Dash slid into the vehicle. Inside, it was aggressively cool. Her shirt nearly froze to her skin. "Can I get drive-through?"

To his credit, Díaz didn't ask her about the case at all. She asked him things, like when he'd started with the company (15, fruit packing; the company sent him to school),

She'd seen the warehouses on her way in. The miles of razor wire. The drones circling above.

and how long he'd been managing the pistachio fleet (two years), and how well he knew these machines (pretty well; they'd been on the job longer than him). He watched her inhale four tacos de guisado with extra green salsa and a bucket of hibiscus tea. Then he left her at her doorstep.

Dash drew a cold bath. It was lukewarm when Batstone's call sloshed her awake. "Well?"

"I'm fucked." She stepped out of the tub. "The model is performing fine. I think it's mechanical."

"They showed us the diagnostics. It's not. First principles, Dash. What do the machines do?"

Dash peeled back the sheets on her bed and slid between them. "They collect the pistachios."

"Is that all?"

She pictured herself in the orchard. The heat. The dry earth under treads. The thunderous shuddering of the trees and the scatter of dust and shells. A harvest like a war. "They move along, shaking trees until pistachios come down. When the receivers are full, they deposit the harvest, recharge, and start again somewhere else."

They were silent together for a few moments: Dash in bed in California, Batstone wherever he was this week. Geneva, maybe. He was in Geneva a lot lately. He cleared his throat. "Is there another fleet of the same vintage for comparison?"

She shook her head, even though he couldn't see her. "Not the same manufacturer, no. That's the problem. If a nascent intelligence is emerging, it's on this manufacturer and their software. They don't like me."

"They just don't know you."

"Yeah, if they knew me, they'd really hate me."

"Darling. If they knew you, they'd be terrified."

Before Andrew could wake her up, a pounding sounded on Dash's door. Wakefulness trickled icily down her nerves. She rolled herself in her sheet and shuffled to the door. Outside stood Díaz.

"What is it?"

"We've got a problem," he said. "Someone tried to break into the vault."

She yanked the door open. "Where's Gleason?"

Díaz had tacos and nitro waiting in the car. They pushed the limit on the 99, crisscrossing the ghost of the Kings River. On this side of daylight, the company town was theme park Americana, gilded by Golden State dawn.

The vault remained secure. That was the good news. But everything else was bad: a truck had run into the building, knocking out its main power supply. The building had run on wall batteries all night. If the batteries themselves were compromised, Dash would have to start the simulations all over again. They might need a whole new download. And who knew what had happened to the machines in the 24 hours since she'd gotten there? If there was an intelligence present, Gleason's people could have wiped it by now, claiming that it was just cleanup, that they couldn't guess she'd need a new copy. She might have lost the mind.

"This is just terrible," Gleason simpered when he pulled up. "This sets the whole evaluation process back, doesn't it?"

"Don't count on it," Dash said. "If there's an emergent intelligence on those machines, I'm going to find it. And if I find out you tampered with any part of the process, every tractor, every plow, every goddamn riding mower your company codes is going to lose its certification."

Gleason blinked widely with his colorless

lashes. "Surely you don't think that I had anything to do with this. I was with Mr. Stephens all evening. I stayed at his ranch after dinner."

Of course. Dinner. They knew she couldn't go. They knew exactly when she'd be sleeping. And they'd alibi'd themselves accordingly. Moreover, Díaz was helping them.

Dash circled around to the place where the cops weren't, and rang Batstone. "I'm being set up."

"Already? California is more exciting than I thought."

"I'm serious. There's something in there. I don't know what it is, but the manufacturer is trying to hide it and I need every shred of evidence I can get. I'm going back in to see if I can recover anything. Check?"

"Check."

Dash rang off and headed back to the bank. By now Stephens was there too. "This is less than ideal," he said.

"We're ready to open the vault," one of the officers said.

"I have protocols for that." Dash made for the door. She flashed her watch. "I'm the analyst in charge. The mind in that vault is my op."

When Dash reentered the vault, her heart sank. All the simulations were hanging. The power must have cut out during the switch between sources. At the very best, she'd have to start the whole process over again, and that was if the downloaded mind wasn't irretrievably damaged.

She took a closer look at the screen, rubbed her eyes and looked again. All the simulations had frozen in place. But the time stamp wasn't last night.

It was a year from when the machines had first stopped. To the day.

Frowning, she pulled up the documentation on the machines. She waved through technical manuals and went straight to demonstration video. Onscreen, the shakers and receivers moved from tree to tree, coaxing the nuts from the leaves. Drone footage. Time-lapse. Suns rising and setting through a rising cloud of dust and profit. Acre by acre, day after day. Deposit. Recharge. Start again.

She closed her eyes and imagined the orchard. The stars. The silent, empty machines. When she opened her eyes, she was staring at her own footprints across the gleaming floor of the vault. They were the only dust in the room.

Dash exited the vault. Stephens and Gleason each asked her something, but she made for Díaz's ride instead. It was still a pristine white. And so were the other rides: silver and blue and black and gold and … clean.

Dash turned to Stephens. "How do they recharge?"

Stephens blinked. "The same as all our other robots. They take themselves to a power hub."

"Where's the power come from?"

Stephens pointed. "Our solar farm. Just over that ridge. The land got too dry after we moved the river. So we made it useful again."

Dash frowned. "You moved the river?"

"We diverted it. It was our land. Our river." Stephens shrugged. "I needed it to feed the trees. And the trees were somewhere else."

Dash stared across the parking lot, across the town. It was so clean. Like a backlot. Not a speck of dust anywhere. She looked at Díaz. "When was the last rainfall?"

"Two months ago? Almost three."

She saw herself in the plate glass windows of the former bank. The windows should have been dirty. Filthy. The whole town should have been choking on dust. No rain, no river, nothing but sun and dry soil for miles. But the air was clear. The sky was blue.

Dash marched back into the vault. Reunited with her devices, she rang Batstone again. "Is there an issue with battery half-life in this model?" she asked. "Where low charges mean progressively shorter life spans?"

It took him a moment. "Yes."

Dash squeezed her eyes shut. Silence stretched between them. Sweat dripped down her back. She laid a hand on the cold steel of the vault door and shut her eyes. "Do the batteries come from Gleason's company?"

"You've picked up a scent, haven't you?" She heard the smile in his voice. "They come from a third-party supplier."

She pressed her forehead against the steel. Saw the orchard. The sun. The stars. The machines below. The simulations had run, kept running. It wasn't a power cut that had stopped them. The machines themselves would stop again next year. After days of shaking and harvesting and recharging, they would simply—

"Check the manufacturer for a patent on a battery design." The hairs on her arms rose. "Gleason's company doesn't want the mind. They want to break into the battery business, so they're not replacing the existing batteries, to create demand."

The silence ticked by. She heard him lick his lips. "There does appear to be a patent pending."

"The machines need the air to be clear," she whispered. "They need the air to be clear so the farm can bank more energy, so the batteries can charge. Which means they can't shake the trees. Because if they shake the trees, the dust will rise. The dust will hang in the air and coat the cells. Because the rain isn't coming. And they'll starve. We'll all starve, together."

"My darling Dash," Batstone said. "Please come home. Bring our new friend with you."

Dash found her own ride back to the hotel. She didn't even pause to bid farewell to Stephens and Gleason, just said she'd forgotten something in her room. She could send her pleasantries from the plane. They didn't even notice the briefcase weighing down her backpack.

Díaz was waiting outside her room. "I wasn't part of it."

"That's nice," she said, and pushed into her room. She swept the entirety of her bathroom counter into an open carry-on and tapped it shut. She patted her document pocket and quit the room.

"I like you," he said, from the doorway.

She hauled her bag behind her. "I'm leaving."

"No, I mean it. I like you. I wasn't part of this. Whatever it is. I was operating in good faith. I promise."

Dash sighed. "Okay."

"My family's been here since the grape strikes. I'm not … I care if …"

"You care if your employer is exploiting an emergent consciousness without remuneration, which is effectively child slave labor."

"Yeah. That." He looked at her bag. "I pushed to bring you here. I wanted someone to come. I felt, or I've been feeling …" He rubbed the back of his neck. "They're different. Than they used to be. Aren't they?"

"That's a matter of faith, Mr. Díaz."

She let herself seethe for a good 20 minutes. Then she called Andrew. "I'm coming home."

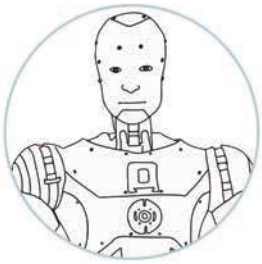
"Good," he said. "Your handler will be pleased. I'll tell your place to get ready."

"I wish you could be there," Dash said.

"If wishes were horses, then beggars would ride."

Madeline Ashby is a science fiction writer and futurist living in Toronto. Her most recent novel, Company Town, is available now from Tor Books.

By Sarah Cooper



Employee Performance Review

EMPLOYEE NAME
TED-5000728

DIRECT SUPERVISOR
JENNY-8675309

DEPARTMENT
Customer Service

EMPLOYEE TITLE
Customer Service Rep

NEXT LEVEL SUPERVISOR
Michelle Howitzer

DATE OF REVIEW
April 2, 2034

QUANTITY OF WORK

The quantity of customer calls TED handles is consistent with what's acceptable for this model. A system upgrade in June resulted in higher productivity.

QUALITY OF WORK

Quality of work varies greatly based on how irate the customer is. Some customers do not respond well to TED's eerily consistent tone, especially in winter months.

INITIATIVE

Too much. Constantly takes on additional tasks. Needs to be aware of how this affects human counterparts.

COMMUNICATION

Oral communication is cold and off-putting; however, TED is getting better at detecting sarcasm.

TEAM BUILDING

Does not engage with activities outside of work; refuses to engage in drinking or karaoke.

FEEDBACK RECEIVED

ATTENTION TO DETAIL	1	2	3	4	**5**	n/a
ATTENTIVENESS IN MEETINGS	1	2	3	4	**5**	n/a
WORK ETHIC	1	2	3	4	**5**	n/a
WORK / LIFE BALANCE	1	2	3	4	5	**n/a**

WORKS LIKE A MACHINE

ADDITIONAL NOTES

We received some complaints about TED spending too much time flirting with the printer.

RECOMMEND FOR PROMOTION?

Not at this time.

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MIT Technology Review

35 Innovators Under 35

Meet Jonas Cleveland, CEO of COSY, and the other young inventors, pioneers, and entrepreneurs shaping the future for all of us.


Connecting vehicles
Protecting pedestrians
Making cities smarter
Reducing accidents
Maximizing efficiency
battelle.org/tech

BATTELLE

It can be done

35 Innovators Under 35

We've been presenting our list of innovators under 35 for 18 years, which is long enough to spot some trends. Social media wasn't on many people's minds when the list was born, but there was a run there where just about every year we paid tribute to the creator of the latest hot social-networking site (including, in 2007, the kid who dreamed up a personal profile site called Facebook in his Harvard dorm room).

You won't find a lot of artificial-intelligence innovation in the early days of the list, but AI now dominates—in the past two years alone honorees have harnessed AI for personal assistants, robotics, gaming, self-driving cars, and face recognition, and to fight deadly infections, cholera, and Parkinson's.

And the list has grown more gender equitable. It was once male-dominated, but this year, for the first time, it includes more women than men.

The competition generates nearly 600 nominations every year. A panel of editors at *MIT Technology Review* filters the list down to what it feels are the 100 strongest candidates, whose work is then evaluated by a panel of 36 judges (see list at right), with expertise in areas like AI, biomedicine, nanotechnology, electronics hardware, and energy. Based on their ratings, the final list of 35 emerges.

We hope the list, taken as a whole, gives you a sense of what's coming next, and what kinds of people are making it happen.

—The Editors

JUDGES

Anima Anandkumar
Bren professor of computing and mathematical sciences, Caltech; principal scientist, Amazon AI

Zhenan Bao
K.K. Lee professor of chemical engineering, Stanford University

Burcin Becerik-Gerber
Associate professor of civil and environmental engineering, University of Southern California

Charles Bergan
VP, engineering, Qualcomm Research

David Berry
General partner, Flagship Pioneering

Joseph Bolen
Chief scientific officer, PureTech Health

Ed Boyden
Y. Eva Tan professor in neurotechnology, MIT

Greg Brockman
Cofounder and CTO, OpenAI

Yet-Ming Chiang
Kyocera professor, department of materials science and engineering, MIT

James Collins
Termeer professor of medical engineering and science, MIT

John Dabiri
Professor, school of engineering, Stanford University

Jonathan Downey
Founder, Airware

Gozde Durmus
Postdoctoral research fellow, Stanford University

David Fattal
Founder and CEO, Leia

Adrienne Porter Felt
Engineering manager, Google Chrome

Tanuja Ganu
Cofounder, DataGlen

Javier García-Martínez
Director, molecular nanotechnology laboratory, University of Alicante, Spain

Julia R. Greer
Professor of materials science, mechanics, and medical engineering, Caltech

Zhen Gu
Professor of bioengineering, UCLA

Ilan Gur
Founding director, Cyclotron Road

Christine P. Hendon
Associate professor of electrical engineering, Columbia University

Eric Horvitz
Technical fellow and director, Microsoft Research

Quoc Le
Research scientist, Google

Hao Li
CEO, Pinscreen; assistant professor of computer science, University of Southern California

Bill Liu
CEO, Royole

Mick Mountz
Founder and CEO, Kiva Systems

Carmichael Roberts
Entrepreneur and general partner, North Bridge Venture Partners

John Rogers
Professor of materials science and engineering, biomedical engineering and neurological surgery, Northwestern University

Olga Russakovsky
Assistant professor of computer science, Princeton University

Rachel Sheinbein
Venture partner, Lemnos

Cyrus Wadia
Vice president, sustainable business and innovation, Nike

Jennifer West
Fitzpatrick family university professor of engineering, Duke University

Jianxiong Xiao
Founder and CEO, AutoX

Jackie Y. Ying
A*STAR senior fellow NanoBio Lab, Singapore

Feng Zhang
Core institute member, Broad Institute, MIT and Harvard

Ben Zhao
Neubauer professor of computer science, University of Chicago

1

Pioneers

Their innovations are leading the way to better gene editing, smarter AI, and a safer internet.

Joy Buolamwini

28 MIT MEDIA LAB AND ALGORITHMIC JUSTICE LEAGUE

When AI misclassified her face, she started a movement for accountability.

As a college student, Joy Buolamwini discovered that some facial-analysis systems couldn't detect her dark-skinned face until she donned a white mask. "I was literally not seen by technology," she says.

That sparked the research for her MIT graduate thesis. When she found that existing data sets for facial-analysis systems contained predominantly pale-skinned and male faces, Buolamwini created a gender-balanced set of over a thousand politicians from Africa and Europe. When she used it to test AI systems from IBM, Microsoft, and Face++, she found that their accuracy varied greatly with gender and skin color. When determining gender, the error rates of these systems were less than 1 percent for lighter-skinned males. But for darker-skinned female faces, the error rates were as high as 35 percent.

In some cases, as when Facebook mislabels someone in a photo, such mistakes are merely an annoyance. But with a growing number of fields coming to rely on AI—law enforcement is using it for predictive policing, and judges are using it to determine whether prisoners are likely to reoffend—the opportunities for injustice are frightening. "We have to continue to check our systems, because they can fail in unexpected ways," Buolamwini says.

A former Rhodes scholar and Fulbright fellow, she founded the Algorithmic Justice League to confront bias in algorithms. Beyond merely bringing these biases to light, she hopes to develop practices to prevent them from arising in the first place—like making sure facial-recognition systems undergo accuracy tests. *—Erika Beras*

"I was literally not seen by technology."

Alexandre Rebert

28 FORALLSECURE

He asked, what if a computer could fix itself?

When a computer system gets hacked, people typically fix the problem after the fact. Alexandre Rebert created a machine that can fix itself as the attack is happening.

Rebert recognized that computers may lack creativity, but they're good at doing things quickly and on a massive scale. His system, called Mayhem, can analyze thousands of programs simultaneously, doing in a few hours what might take a human expert years to accomplish.

Mayhem, an autonomous system, does this by combining two techniques. The first is called coverage-based fuzzing—a standard in automated security testing, in which data is thrown at a program to see if an input triggers new behavior. It's essentially scanning and searching in a fast way. The second, symbolic execution, analyzes the program in a slower, more nuanced way. The approaches complement each other, making the combination better than other techniques.

Rebert led the team creating Mayhem while working with ForAllSecure, the Pittsburgh-based cybersecurity company he cofounded. The company's work and mission stem from his research at Carnegie Mellon. He thinks his invention could be especially useful for vulnerable systems like power grids, hospitals, and banks.

"There is an increasing amount of software in our lives," says Rebert. "And depending only on human expertise is insufficient and dangerous."

—Erika Beras

LAKISHA COHILL (BUOLAMWINI); COURTESY PHOTO

Nabiha Saklayen

28 CELLINO BIOTECH

She developed a way to edit genes with cheap lasers.

Gene editing is invaluable in correcting mutations like the one that causes sickle-cell anemia. But biologists need better ways to get DNA and other ingredients into cells. Typically, the gene-editing recipe is introduced by viruses, which can have dangerous side effects, or during electroporation, a technique that uses strong electrical pulses and kills many of the cells in the process.

Lasers offer a gentler alternative, but those methods have had their own drawbacks. The lasers used have typically been very powerful and expensive, and capable of injecting only one cell at a time – too slow for clinical applications.

Nabiha Saklayen's innovation was to design nanostructured add-ons to the laser system that deliver pulses of laser light to large numbers of cells at once, making it possible to dose them with gene editors at clinically useful speeds. Her process doesn't require an expensive laser, though it took her a while to convince other researchers and her advisor that relatively cheap ones were powerful enough. "It doesn't matter to the cell," she says.

Saklayen has now founded a company, Cellino Biotech, to commercialize her idea and use gene-editing tools to engineer cells.

Trained as a physicist, she is unusually comfortable with moving between scientific fields, including laser physics, nanomaterials, and synthetic biology. She credits her upbringing in Saudi Arabia, Bangladesh, Germany, and Sri Lanka with her adaptability. "I'm comfortable in new places, and at the interface of different fields," she says.

– Katherine Bourzac

PORTRAIT BY SIMON SIMARD; STYLING BY LAURA DILLON

Chelsea Finn

25 BERKELEY ARTIFICIAL INTELLIGENCE LAB

Her robots act like toddlers—watching adults, copying them, and learning how to learn.

Chelsea Finn is developing robots that can learn just by observing and exploring their environment. Her algorithms require much less data than is usually needed to train an AI—so little that robots running her software can learn how to manipulate an object just by watching one video of a human doing it.

Finn's robots act like toddlers, watching adults do something and copying them. A wooden shape-sorting toy in her lab shows evidence of the process: marks from where a robot repeatedly bashed a red cube before learning to place it inside the square hole.

Her ultimate goal is to create robots that can be sent off into the world and acquire a general set of skills—not because they've been programmed for those tasks but because they've been taught to learn by observing. This might mean factory robots that wouldn't have to be trained by teams of engineers, or AI systems that recognize objects without being trained on labeled images.

Finn thinks a good intermediate goal for her robots is to teach them how to set the table. The first step is to make robots that can learn how to arrange multiple objects. "In many ways, the capabilities of robotic systems are still in their infancy," she says. "The goal is to have them gain common sense."

—Katherine Bourzac

Humsa Venkatesh

32 STANFORD UNIVERSITY

She discovered a secret to cancer growth that could lead to a new class of drugs.

HUMSA VENKATESH'S RESEARCH revealed how cancers hijack the activity of neural networks to fuel their own growth. Her discovery sparked a novel area of research targeting a type of activity seen in many different types of cancer. "These neuronal systems are signaling inputs that instruct how the tumor grows and functions," she says. The results could lead to therapies that work against tumor cells in all their diversity.

When Venkatesh was a teenager in California, her uncle, who lived in India at the time, learned he had kidney cancer. Though he sought treatment in both India and the US, the only options available to him were standard radiation and chemotherapy, neither of which was effective. He died less than two years after the diagnosis. The experience made Venkatesh realize how little doctors understood the fundamental mechanisms of tumor growth.

So instead of becoming a doctor, as she'd originally hoped, she devoted herself to studying that. "I wanted my contribution to be not just treating these patients on an individual level, but really advancing cancer research in a way that would help us come up with new ways to treat [them]," she says.

Now Venkatesh is harnessing tumors' essentially parasitic behavior within their environment to develop drugs that might neutralize the way they exploit neural networks. These therapies could be pushed into clinics faster than some others because prototypes of such drugs already exist—they were developed for other purposes before scientists found out about their potential in cancer treatment. *—Yiting Sun*

John Schulman

30 OPENAI

Training AI to be smarter and better, one game of Sonic the Hedgehog at a time.

John Schulman, a research scientist at OpenAI, has created some of the key algorithms in a branch of machine learning called reinforcement learning. It's just what it sounds like: you train AI agents in the same way you might train a dog, by offering a treat for a correct response. For a machine, the "treat" might be to rack up a high score in a video game.

Which explains why Schulman is so excited about the 1991 video game Sonic the Hedgehog. The game, he says, is a perfect benchmark for testing how well new machine-learning algorithms transfer learned skills to new situations. Since Sonic is the world's fastest hedgehog, the game moves rapidly, and it also depicts some interesting physics. Once an AI agent learns how to play, it's easy for researchers to test its ability to transfer that knowledge to different scenarios.

These algorithms, once trained, might be applied in the real world, and they can be used to improve robot locomotion. Traditional approaches have been specialized for certain situations—which means that on new terrain, a robot programmed using older methods might fall down. One that uses reinforcement learning, Schulman hopes, would be able to get back up and try new things until it solves the problem.

—Katherine Bourzac

KOJO ACQUAH (FINN); SAAHIL MEHRA (VENKATESH); ERIC LOUIS HAINES (SCHULMAN)

Julian Schrittwieser

25 DEEPMIND

AlphaGo beat the world's best Go player. He helped engineer the program that whipped AlphaGo.

A few years ago, when Julian Schrittwieser joined the Google-owned artificial-intelligence firm DeepMind, the board game Go was often called the Holy Grail of machine learning. The two-player game, which originated in ancient China, was so unconstrained by rules and so driven by intuition that many thought it would take a decade for AI to best the world's top players. But in March 2016, a program developed by Schrittwieser and his DeepMind colleagues defeated South Korea's Lee Sedol, the world Go champion, in a best-of-five series that drew more than 100 million viewers. Go enthusiasts called it the match of the century.

Schrittwieser and his teammates followed this up with an even more impressive accomplishment. In October 2017, their new program, AlphaGo Zero, defeated the earlier program, AlphaGo, 100 games to zero. Unlike AlphaGo, which learned the game by studying the play of humans, AlphaGo Zero learned by playing against itself – a feat with major implications for artificial intelligence. "With AlphaGo Zero, we see that even in areas where we don't have human knowledge, we can bootstrap that knowledge and have a system that learns on its own," Schrittwieser says.

"Even in areas where we don't have human knowledge, we can bootstrap that knowledge and have a system that learns on its own."

Schrittwieser, an Austrian native, is the lead software engineer on the AlphaGo Zero project. He is also a driving force behind a third DeepMind initiative, AlphaZero – a more generalized algorithm that has already mastered Go, chess, and the Japanese board game Shogi. The push toward generalization, Schrittwieser says, is key to DeepMind's quest to build intelligent machines that are independent of human intuition – thereby devising better solutions to problems where the approach might otherwise be inhibited by human biases. Ultimately, he believes, this could lead to entirely new, AI-driven innovations in fields from pharmaceuticals to materials science. *—Jonathan W. Rosen*

MIKE DODD (SCHRITTWIESER); COURTESY PHOTO

Alessandro Chiesa

30 UNIVERSITY OF CALIFORNIA, BERKELEY

A cryptocurrency that's as private as cash.

For all the promise of blockchain, there's a problem that comes with treating all transactions as public information: some of that stuff is just nobody's business. But with Zcash, a cryptocurrency cofounded by Alessandro Chiesa, transactions can be not only secure but as anonymous as handing someone a $20 bill from your wallet.

That's because Zcash employs a cryptographic protocol called a succinct zero-knowledge proof (see "10 Breakthrough Technologies 2018: Perfect Online Privacy")—that is, an efficient way to convince both parties to a transaction that something is true without divulging any other information.

Zcash has huge implications for transactions that might otherwise reveal a buyer's or seller's location, medical information, or other private data. It allows people to do transactions online without risking their privacy or exposing themselves to identity theft. Zcash, which Chiesa launched four years ago, now has a market cap of over a billion dollars.

—Dan Solomon

2 Visionaries

They look at things in new ways, unlocking powerful and sometimes unconventional uses of technology.

Niki Bayat

32 AESCULATECH

She invented materials that can heal eyes by sealing up traumatic injuries.

Growing up in Iran, Niki Bayat always wanted to use her aptitude in engineering to help people suffering from disease – especially after her father developed glaucoma and was unable to have eye surgery because of other health issues. She placed eighth in Iran's countrywide university entrance exams and majored in chemical engineering at the country's top university. For grad school, she set her sights on the University of Southern California and joined a collaboration between the labs of renowned chemist Mark Thompson and Mark Humayun, who developed the first artificial retina. "I convinced them that I could bridge the gap between polymer chemistry and biomedical engineering," she says.

She did just that, using her chemical engineering expertise to develop materials that can help repair traumatic eye injuries and deliver ocular therapies. Bayat has created squishy, biocompatible polymers called hydrogels that become extremely sticky at body temperature, adhering as strongly as superglue. In cases of eye injury, they can be injected in the field, quickly sealing the wound to prevent blindness. Then, back at a hospital, a surgeon can flush the sealant with cold saline, remove it, and suture the wound. Bayat has also designed versions of these materials that can release glaucoma medication or antibiotics in a controlled manner.

In 2016, while still working on her PhD, Bayat started AesculaTech to commercialize these drug-delivering materials, which can be inserted into the tear ducts and release medication over periods of months – potentially preventing the need for patients to apply eye drops multiple times a day. AesculaTech plans to first seek approval for polymer devices to treat dry eye before trying to introduce drug-releasing versions. Her ultimate goal, she says, is to come up with a new and better treatment for glaucoma.

—Katherine Bourzac

Prineha Narang

28 HARVARD UNIVERSITY

Her research on materials at the smallest scale could lead to a new generation of technologies.

Prineha Narang seeks to build technologies by starting small: with the atom.

As an assistant professor of computational materials science at Harvard, Narang studies the optical, thermal, and electronic behavior of materials at the nanoscale. Her research in how materials interact with light and other forms of electromagnetic radiation could drive innovations in electronics, energy, and space technologies.

Narang's work builds on decades of advances in nanoscience that have brought the field closer to a long-held goal: the ability to engineer materials atom by atom.

Yet since its emergence in the 1980s, the discipline has focused mainly on nanostructures at or near equilibrium—their lowest state of energy. At the temperatures they encounter in nature, however, most materials are away from equilibrium, in so-called excited states, which remain poorly understood at the quantum level. "There's so much more we can do with excited states that has just not been tried yet," Narang says.

By studying these excited states, Narang is developing approaches that could lead to vastly improved materials. Applications could include improved reflectors and lenses for telescopes, lighter cell phones with better cameras, or synthetic fuels designed at the atomic level. *—Jonathan W. Rosen*

ELIZA R. GRINNELL AT HARVARD SEAS (NARANG); COURTESY PHOTO

CELESTE SLOMAN

Brenden Lake

31 NEW YORK UNIVERSITY

Getting machines to learn in the fast and flexible ways that humans can.

Brenden Lake created an AI program that can learn novel handwritten characters as well as a human can after seeing just a single example. That might seem mundane in a world where AI controls self-driving cars and beats the world's best Go players. But today's state-of-the-art deep-learning approaches train on thousands of examples and aren't great at transferring their learning to new problems. A human who's shown an unfamiliar object once, on the other hand, will be able to recognize a new example, draw it, and understand its various parts.

So Lake took inspiration from cognitive psychology. Instead of feeding his program thousands of examples of letters, he taught it how handwriting works. He showed his model motion-capture recordings of humans drawing letters from 30 alphabets so it could learn what pen movements are used to make strokes, how many strokes characters typically have, and how strokes are connected. When shown a character from an unfamiliar alphabet, the model can recognize and reproduce that character just as well as a person.

He's applied the same approach to get machines to recognize and reproduce spoken words after hearing one example, and also to mimic how people creatively ask questions when solving a problem.

Getting machines to learn the way humans do could prove crucial for AI applications where training on big data isn't feasible. "If we want to have smart robots in the home, we can't pre-train or preprogram the robot to know everything out of the box," Lake says. "Children pick up new concepts every day, and a truly intelligent machine must do the same." *—Edd Gent*

Marzyeh Ghassemi

33 UNIVERSITY OF TORONTO

Using AI to make sense of messy hospital data.

After collaborating with doctors in the intensive care unit at Beth Israel Deaconess Medical Center during her PhD studies, Marzyeh Ghassemi realized that one of their biggest challenges was information overload. So she designed a suite of machine-learning methods to turn messy clinical data into useful predictions about how patients will fare during a hospital stay.

It wasn't easy. Areas where machine learning excels typically have huge, carefully labeled data sets. Medical data, on the other hand, comes in a bewildering variety of formats at erratic frequencies, ranging from daily written doctors' notes to hourly blood tests to continuous heart-monitor data.

And while vision and language tasks are innately easy for humans to grasp, even highly trained medical specialists can disagree on diagnoses or treatment decisions. Despite these challenges, Ghassemi developed machine-learning algorithms that take diverse clinical data and accurately predict things like how long patients will stay in the hospital, how likely they are to die while there, and whether they'll need interventions such as blood transfusions or ventilators.

This fall Ghassemi joins the University of Toronto and the Vector Institute, where she's hoping to test her algorithms at local hospitals. *—Edd Gent*

Menno Veldhorst

33 DELFT UNIVERSITY

He figured out how to make workable quantum circuits on silicon—a feat previously considered impossible.

Menno Veldhorst has invented a faster path to real-world quantum circuits by making it possible for them to be printed on silicon – the way computer chips have been made for decades.

Quantum computers would allow powerful calculations that no traditional computer is capable of, but before Veldhorst's innovation, it was considered impossible to make semiconductor-based quantum circuits on silicon that would be stable enough for useful computation. These machines – which are governed by the strange physics of subatomic particles – have instead been built with esoteric materials, including superconductors, that are easier to control in their fragile quantum states. The trade-offs: working with such technology is expensive, and producing such circuitry at scale would require entirely new industrial processes.

Veldhorst, a researcher at Delft University in the Netherlands, has found a way forward with the most replicated manmade structure on the planet – the transistor. He was able to demonstrate calculations on the basic units of quantum information, known as qubits, in silicon semiconductors.

Now, thanks to Veldhorst's breakthrough, Intel is printing hundreds of thousands of such simple systems on the same type of 300-millimeter wafers the company uses to make its conventional chips. This means collaborators at Intel can increasingly spend their time on the microelectronics and algorithms necessary for complete quantum computers rather than working through the basic physics.

What's most exciting to Veldhorst is that – just as with the transistor and the computer itself – a flood of quantum computers will need to be built just to figure out what they are capable of. His research has allowed just that.

—Russ Juskalian

ERIC BENJAMIN MUNSON (GHASSEMI); MARIEKE DE LORIJN (VELDHORST)

Adam Marblestone

31 KERNEL

He wrote the book on how to record every neuron in the brain.

Adam Marblestone wants to make the brain machine-readable. So he worked out the physical limits of what's possible in recording brain activity and is now using that knowledge to set technology strategy at Kernel, a startup with $100 million in funding that's building neural interfaces for humans.

As a PhD student, Marblestone was a lead author of a paper now considered a foundational strategic document for researchers building technology to read brain activity. Using the mouse brain as a model, he identified the engineering problems we'll have to solve to simultaneously measure the activity of every neuron in the brain.

"It's all about how do we, in the approaches that we take to studying the brain, somehow try to match the complexity of the brain itself?" he says.

As chief strategy officer at Kernel, he's marshalling a network of leading researchers to identify the most promising approaches for making neural interfaces that can help us understand and treat neurological diseases. One day they could even make it possible to merge our brains with machines.

—Edd Gent

Shehar Bano

31 UNIVERSITY COLLEGE LONDON

She made state censorship beatable by revealing the technology it relies on.

SHEHAR BANO MADE IT POSSIBLE TO fight state censorship of the internet—by pioneering the first systematic study of how it happens.

It all started when Bano's homeland of Pakistan blocked YouTube in 2012. "Previously, people were under the delusion that this was magic," she says of the inner workings of such restrictions. But she wanted to understand—and defeat—them.

So Bano probed three years of ISP data from Pakistan, and she experimented with ways to circumvent China's Great Firewall. What she found was a variety of relatively basic technical restrictions, such as censors looking for any request to load a specific website and then sending signals to both the website's servers and the surfer's browser to end the request. Understanding this let her devise ways around the restriction without resorting to encryption, like sending an initial, fake request that the censor would see but ignore because of a misspelling—allowing the real request to slip through in the meantime.

Bano not only analyzed online censorship; she also looked into how users of anonymization and security software like Tor and ad blockers are treated differently from unprotected surfers, whether that means a worse user experience or an outright ban.

Bano has joined a wave of computer scientists working to protect the freedom of online communication. As a postdoc at University College London, she's increasingly working with blockchain-based systems, like the smart-contract platform Chainspace, to improve online security and transparency by allowing transactions that are difficult for outside parties to monitor. *—Russ Juskalian*

Archana Kamal

34 UNIVERSITY OF MASSACHUSETTS, LOWELL

She solved a big problem in quantum computing by shrinking the components.

As quantum computing starts to move from the lab to the factory, companies from Google to Intel are struggling to solve a tricky problem: how to faithfully steer the quantum information such systems spit out to traditional computers. Doing so is important since quantum systems, which are expected to have a profound impact on cryptography and other fields, will probably be useful only if regular computers can read their calculations.

Archana Kamal, an assistant professor at UMass Lowell, solved the problem. Kamal demonstrated that quantum information could be steered and amplified for transmission before leaving the device where it was processed. Previously, the transmission required large magnets and complicated devices too big to fit on a single chip, leading to data latency and loss, a major impediment in scaling up current qubit systems.

Kamal's innovation was to slightly alter the path of the transmission of light signals carrying information so as to shrink the components from the size of a quarter to a few micrometers. "That's a huge difference," she says. "Our schemes enable the bulk of quantum signal processing to be done on-chip while preserving the high fidelity of the signals."

—Russ Juskalian

ADRIENNE JACOBSON (MARBLESTONE); IMPERIAL STUDIO, LONDON (BANO); COURTESY PHOTO

3 Humanitarians

They see technology as a way to bring about a safer, healthier, and more equitable world.

Hera Hussain

28 CHAYN

Her tech nonprofit makes it easy for women to build a domestic-abuse case without a lawyer.

Hera Hussain is empowering women around the world via a simple combination of social and technological innovation: enlisting volunteers to crowdsource multilingual online guides covering topics like how to build a domestic-abuse case without a lawyer, or how to identify psychological manipulation.

It all started after Hussain tried to help two friends escape abusive marriages. "You would think in the UK it would be easy to find information about how to get a divorce, how to apply for asylum, what are the laws to apply for child custody," she says. "But it was frighteningly difficult to get that information."

In 2013 Hussain founded the open-source, nonprofit organization Chayn in her spare time – to make the missing information easy to find and understand. Today, 70 percent of Chayn's 400 volunteers are survivors of violence and oppression themselves. Their guides are built largely from crowdsourced research and firsthand experience of the overlapping psychological, cultural, and legal complexities involved in oppression against women.

Hussain says she's lost count of the times she's been lectured – mostly by men – that Chayn's guides shouldn't be written by people without legal or academic backgrounds. "You get talked down to a lot," she says. She likes to counter their arguments with the example of a woman from India who for years was trying to figure out how to leave her abusive marriage. All the resources the woman found online were written by Indian lawyers, almost all men, lamenting that women took advantage of divorce laws rather than be dutiful wives.

Hussain continues to push Chayn to harness appropriate technologies to deepen its reach. A new chatbot, for instance, guides visitors to the most relevant information in as few clicks as possible. *—Russ Juskalian*

Mustafa Suleyman

33 DEEPMIND

Working to alleviate human suffering through AI.

Mustafa Suleyman cofounded the AI company DeepMind out of a desire to have as broad an impact on society as possible. AI, he decided, was the fastest way to do it.

Now Suleyman has launched DeepMind Health to build AI that can better diagnose disease, including systems that detect early-stage eye disease and help analyze mammograms. He's also focusing on how such technology is used by medical clinicians. "The tech community is only just finally catching up in thinking about the ethical impact of these systems," says Suleyman. For instance, will time-pressed clinicians simply defer to the AI's top suggestions without critical evaluation? How will such systems be audited? And how can new medical findings take into account implicit biases in old data used to train the AI? "I think this is going to be the year when Silicon Valley and the technology companies come to really accept the incredible social responsibility that such great power carries," he says.

Last year, Suleyman launched the DeepMind Ethics & Society unit to design systems that anticipate and direct algorithms' decision-making processes and their impact on society.

"The big pivot that technology companies are going to make," he says, "is to ask the question: How do we shape these algorithms so they represent the moral choices that we collectively elect to make?" *—Russ Juskalian*

COURTESY PHOTOS

PORTRAIT BY SIMON SIMARD; STYLING BY LAURA DILLON

Minmin Yen

29 PHAGEPRO

Cholera kills, and vaccines don't always work. She created a better solution.

Cholera affects millions of people annually in the world's poorest communities. It's often treated with antibiotics, but they're not ideal because they harm the bacteria in the gut, and antibiotic resistance is on the rise.

Minmin Yen developed a better solution: bacteriophages, or viruses that specifically target bacteria. What's significant about Yen's intervention is that it works immediately to kill the bacteria and prevent the disease from developing. Existing vaccines, in contrast, can take weeks to work.

Yen, who earned a PhD in molecular microbiology at Tufts University, says bacteriophages have been mostly unexplored because antibiotics are so prevalent, but she thinks it's time for them to play a larger role now that resistant bacteria are so common. She has started a company, PhagePro, to bring her intervention to market. *—Erika Beras*

4 Inventors

They're building the technologies of the future, from stretchy electronics to new ways to test cancer drugs.

Barbarita Lara

32 EMERCOM

An earthquake led her to invent a blend of analog and digital technologies for use when networks are down.

WHEN AN 8.8 MAGNITUDE EARTHQUAKE hit her native Chile in 2010, Barbarita Lara started tinkering. An engineering student at the time, she was struck by the challenges of communication in the quake's aftermath: everyone she knew had become dependent on the internet and cell phones, but most networks were down. Along the Chilean coast, 156 people were killed in a tsunami triggered by the quake—in part because they didn't receive a warning in time.

Eight years later, Lara has a product she thinks can help save lives in the next disaster. Her platform, known by its Spanish acronym SiE, allows smartphone users to receive messages from authorities via encrypted high-frequency audio: a blend of analog and digital technologies designed for use when internet and phone networks aren't working. The SiE platform, which makes use of existing radio infrastructure, also enables smartphones to message each other using mesh, a radio-enabled wireless ad hoc network. Lara's invention was inspired by Morse code, which her father, a cryptologist in the Chilean navy, introduced to her when she was a child. "Sometimes the best solution is very simple," she says.

Emercom, the startup she founded to develop and market the platform, is now in discussions with Chilean disaster management authorities about the prospect of using SiE for future alerts. It's also in talks with a leading telecom about preinstalling SiE on new cell phones.

—Jonathan W. Rosen

"Sometimes the best solution is very simple."

Sheng Xu

34 UNIVERSITY OF CALIFORNIA, SAN DIEGO

Making off-the-shelf electronics stretchable.

Stretchy electronics that can conform to the body no longer have to compromise between electrical and mechanical performance, thanks to some smart engineering by Sheng Xu.

Marrying rigid electronic components with elastic materials is tricky. The mismatch in their mechanical properties generates huge strains, causing them to separate when deformed. That's why most previous research in flexible electronics focused on building new components that are soft and flexible. But Xu didn't see the sense in discarding decades of progress in the electronics industry. "Why not use something that already matured decades ago?" he says. His strategy made it possible to integrate off-the-shelf components into elastic materials to create highly stretchable electronics as capable as their rigid counterparts.

Xu opted to bond only tiny sections of the components to the elastic material and then support them in a fluid-filled capsule. These are joined together with wires configured into long wavy lines that unravel in an ordered way when stretched. He's used the approach to build a lithium-ion battery that stretches by up to 300 percent and a hospital-quality health monitor that conforms to the body as it moves. The latter has been developed into a wearable physiological sensor called BioStamp by a startup called MC10. *—Edd Gent*

COURTESY PHOTOS

PORTRAIT BY KATE WARREN; STYLING BY CARLA PRESSLEY

Shinjini Kundu

27 CARNEGIE MELLON UNIVERSITY

Medical images are so detailed it can be hard to decipher them. Her program can spot what people can't.

Medical images are massively important in diagnosing disease, but as they get more detailed it becomes harder and harder for a human being to interpret them. Shinjini Kundu created an artificial-intelligence system that can analyze them to find patterns undetectable to the naked eye. Her innovation could have a fundamental impact on the way we detect and treat diseases.

"If there are hidden changes and there is a way to detect these invisible patterns, then maybe we have a chance to diagnose diseases early, before symptoms develop," she says.

There are already AI algorithms that teach themselves to spot patterns, but they're not able to explain their reasoning. In medical diagnosis, this can be a limitation: without some knowledge of how and why a disease is developing, it's impossible to address.

Kundu's system allows humans to look through the eyes of the computer to discover otherwise imperceptible patterns that reveal the early disease process. She also trained the AI to pull out the disease markers from the images so that they can be seen on their own. That could help humans recognize them months or years before the onset of illness – so rather than just humans teaching AI, AI can teach us.

—Erika Beras

Shreya Dave

30 VIA SEPARATIONS

Her filtration system could eliminate much of the energy used in industrial separation processes.

Shreya Dave thought her PhD research had no practical applications. It involved molecular filtration membranes made of graphene oxide—which is cheaper and less prone to degrading than the polymers and ceramics used today—but her method was too expensive for the water industry.

Then an article in *Nature* convinced her that the technique could save massive amounts of energy in the industrial processes used to separate chemicals for food, beverages, drugs, and fuel. These processes, it turns out, account for 12 percent of all US energy consumption.

Dave is now the CEO of Via Separations. The technology she and her team designed is meant to replace the current system for separating chemical compounds, which basically amounts to boiling. Dave believes that widespread adoption of Via's filtration material could eliminate anywhere from 50 to 90 percent of the energy used in such industrial processes.

Her company is currently focusing on the food and beverage industry, but Dave thinks if she can prove that the technology is scalable and cost-effective in one industry, that will be the key to succeeding in others.

—Dan Solomon

Will McLean

31 FREQUENCY THERAPEUTICS

Hearing loss in humans has always been irreversible. His innovation may change that.

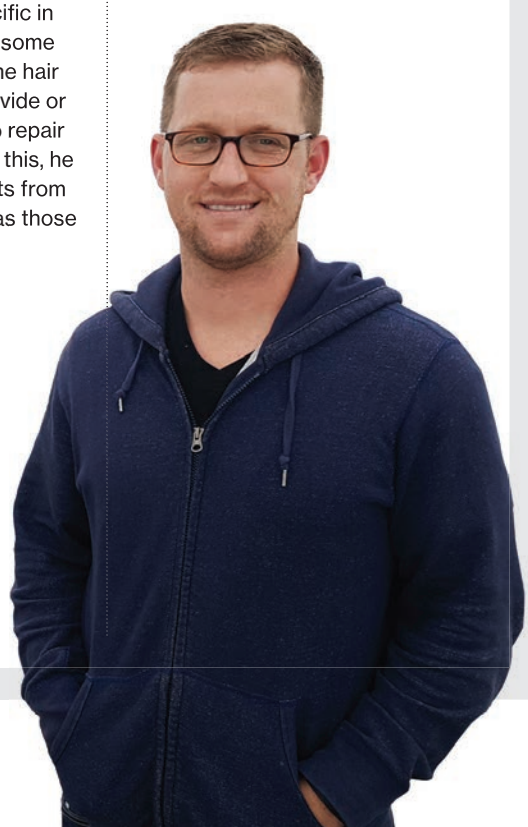
Will McLean believes he's found a fix for a medical conundrum that many thought could never be solved: hearing loss in humans.

McLean's research focuses on the cochlea, the spiral-shaped cavity within the inner ear that's responsible for hearing. At birth, the average human cochlea contains 15,000 hair cells, which detect sound waves and transfer them to the brain. Over time, many of these cells are killed by exposure to loud noise and toxic medications. In mammals, unlike birds, reptiles, and amphibians, they don't naturally grow back. "The inner ear is one of the least regenerative parts of the body," McLean says. "That's why hearing loss is permanent."

McLean, who holds a PhD from MIT in health science and technology, has spent the last decade trying to change that. His early work showed that the inner ear contains distinct progenitor cells – similar to stem cells but more specific in their capabilities – and that some have the potential to become hair cells, though they cannot divide or differentiate on their own to repair damaged tissue. To resolve this, he and colleagues used insights from regenerative tissues, such as those in the intestine. They exposed damaged cochleas from mice to a combination of drugs that can trigger regeneration in these other organs. Surprisingly, their technique not only caused the progenitor cells to proliferate but also induced them to generate new hair cells – the key to restoring hearing.

On the strength of this discovery, McLean and colleagues established Frequency Therapeutics, a startup working to commercialize what he describes as an entirely new mode of medicine. Frequency's technique, known as progenitor cell activation, uses a combination of compounds that essentially unlock the body's ability to heal itself. To date, Frequency has filed 19 patent applications and developed an injectable in-ear therapeutic to combat hearing loss. The treatment has successfully passed human safety trials. *—Jonathan W. Rosen*

"The inner ear is one of the least regenerative parts of the body. That's why hearing loss is permanent."



SIMON SIMARD (DAVE); FREQUENCY THERAPEUTICS (MCLEAN)

Huanping Zhou

34 PEKING UNIVERSITY

Her innovations could make better, cheaper alternatives to silicon solar cells.

THE SOLAR ENERGY INDUSTRY HAS lacked a low-cost, high-performance alternative to silicon for a long time. In recent years, a family of hybrid materials called perovskites has gained attention because they can achieve high power output more cheaply than silicon. But making them work in practice has proved difficult. Early prototypes of perovskite-based solar cells weren't as efficient as conventional silicon cells at converting the energy in sunlight into electricity.

Huanping Zhou developed a series of chemical processes that made perovskite-based solar cells more efficient and cheaper to produce. If they can be mass-produced, her innovation will make solar power much cheaper.

Growing up in the countryside of China, Zhou did not have electricity at home. She and her siblings did their homework by the light of a kerosene lamp. Her childhood experience motivated her to devote herself to solar technology.

The cell Zhou developed converts more than 20 percent of the energy in sunlight, about the same rate as existing silicon panels. Although some other perovskite cells are more efficient, Zhou's invention is important because it makes the manufacturing process easier and cheaper. The cells can be produced at temperatures below 302 °F (150 °C) by spraying or printing a perovskite-based liquid solution onto a substrate such as glass. The process for some other types of perovskite cells requires temperatures around 932 °F.

Perovskite-based solar cells tend to degrade faster than silicon cells, so Zhou is also working on improving their durability. *—Yiting Sun*

Manan Suri

31 INDIAN INSTITUTE OF TECHNOLOGY, DELHI

His computer chips mimic the workings of the human brain.

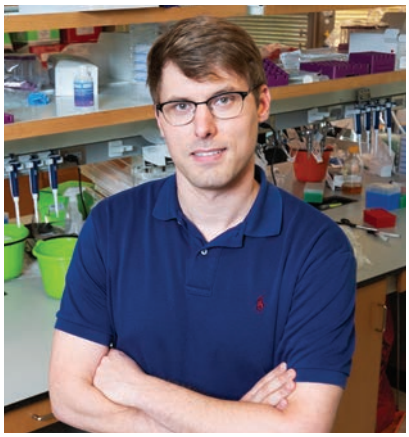
Manan Suri has built key elements of computer chips that mimic the learning ability and energy efficiency of the brain. And he did it by harnessing a quirk of next-generation memory technology.

That technology is known as emerging non-volatile memory (eNVM). Because of peculiarities in their nanoscale physics, eNVM devices often behave in random ways, which in computers is usually a flaw. But Suri realized that this irregularity could help researchers build so-called neuromorphic chips, which emulate the neurons and synapses in our brains.

While transistors store information as *1*s and *0*s, the biological synapses that store information in the brain can take multiple states. That means building computers that behave like the brain traditionally required complicated artificial synapses that can also take multiple states.

Suri recognized that he could harness the inherent variability of eNVMs to build large-scale neuromorphic systems capable of doing supervised and unsupervised learning. He's exploited that irregular behavior for cybersecurity and advanced sensing applications. Earlier this year he founded a startup, Cyran AI Solutions, to build neuromorphic and cybersecurity hardware based on his eNVM research. *—Edd Gent*

PARDEEP (SURI); GEORGIA TECH (DAHLMAN): COURTESY PHOTO



James Dahlman

31 GEORGIA TECH

His method makes it possible to test 300 drugs at once.

FOR DECADES, THE PHARMACEUTICAL industry's approach to finding new cancer therapies has been to put tumor cells in a dish and test drug-delivering nanoparticles (particles between one and 100 nanometers in size), one by one by one, to find one that's effective. Then researchers have to hope that those particles go where they're needed when introduced into a living subject whose body might attack them or break them down.

"The problem is that, forever, people have been testing drug delivery vehicles the wrong way," says James Dahlman, who runs a lab at Georgia Tech.

Dahlman has invented a radically different process that involves encoding each nanoparticle with a DNA sequence that he calls a bar code. Three hundred of those nanoparticles can be injected into a laboratory mouse, and when researchers remove the tumor, they can use gene-sequencing technology to determine how each of the bar codes did, all at once. The difference in volume is staggering. Dahlman says he tested about 30 particles during his entire PhD; in 2018 alone, his lab will hit 3,000. He hopes this technology could mean that a drug designed to treat a tumor in the lung, for example, could go straight to the problem area—rather than making the patient's hair fall out. *—Dan Solomon*

5 Entrepreneurs

Their innovations are creating new businesses and upending the old ways of doing things.

Elizabeth Nyeko

34 MODULARITY GRID

Her energy solution for rural communities in Africa could make grids more efficient everywhere.

Elizabeth Nyeko thinks she's found a solution to one of rural Africa's key development challenges: how to electrify communities in a way that's affordable – and efficient.

As CEO of Modularity Grid, a London-based startup, Nyeko builds technologies that improve the performance of mini-grids, small-scale electricity generation and distribution systems that power homes and businesses in areas where extending national grids is too expensive. Yet mini-grids also have limitations. As Nyeko learned at her previous startup, Mandulis Energy, which built a biomass-fired mini-grid in northern Uganda, the electricity demand of individual customers is very hard to track, which typically leads to overproduction of power, inefficient use of fuels, and inflated electricity prices.

At Modularity Grid, Nyeko designed an intelligent cloud-based platform that enables mini-grid operators to better track and predict individual consumption; it then redirects excess electricity to a specific user in need of constant power, called an "anchor load." At the Mandulis site in Uganda, where Nyeko is piloting her Modularity Grid solution, the anchor load is the village rice mill – which also provides the rice husks used to fuel the mini-grid itself. "If we can deliver just the amount of electricity to people that they need, and redirect the rest to something that creates value for a rural community, we can make mini-grids viable in a low-income setting," Nyeko says.

Nyeko, who was born in northern Uganda but fled from civil war there as a child, is now marketing her solution to other mini-grid providers and is set to begin work with a consortium of German companies, including Siemens, on a second power project in her native country. Eventually, she believes, her solution can also help make national grids more efficient – in Africa and beyond.

—Jonathan W. Rosen

Alice Zhang

29 VERGE GENOMICS

Using machine learning to identify new treatments for Parkinson's and Alzheimer's.

Traditional approaches to drug development for diseases like Alzheimer's, Parkinson's, and amyotrophic lateral sclerosis (ALS) haven't offered patients much. Alice Zhang is trying something new. Her company, Verge Genomics, uses artificial intelligence to identify promising compounds, refining the algorithms with high-quality data from patients and lab tests. She hopes this will be a more effective way to find treatments for intractable neurodegenerative diseases.

Zhang's unorthodox method was inspired when she heard a researcher give a talk detailing how hundreds of genes interact in cancer and wondered whether this "network" approach could apply to neurodegenerative diseases. "Computational biology has provided so much insight about cancer," she says. "The brain is about 10 years behind."

Verge is developing machine-learning models that identify key genes within a disease network and predict which compounds might interfere with their activity. It tests these compounds in animal models and nerves grown from patient-derived stem cells. The company then feeds the results back into the machine-learning model to refine it further. Zhang says seven of Verge's candidate compounds for ALS have slowed cell death in patient neurons in vitro. *—Katherine Bourzac*

TODD JOHNSON (ZHANG); COURTESY PHOTO

JUSTIN MUIR

Jonas Cleveland

31 COSY ROBOTICS

Helping create the shopping robots of the near future.

Jonas Cleveland thinks shopping robots will not only be picking goods off the shelves at massive warehouses but roaming the aisles at local businesses, grabbing products for online orders in stores that are also full of human shoppers.

Cleveland's company, COSY (for Cognitive Operational Systems), is creating the sensor perception system for those robots. Cameras, AI, and mapping technology help make them smart enough to do their job without interfering with the people around them. So if you're shopping in a pharmacy or home improvement store, Cleveland's robots won't bump into you, and if you've ordered online for delivery, the robot that prepares your order will know a six-pack of Diet Coke from a six-pack of Coke Zero. *—Dan Solomon*

Natalya Bailey

31 ACCION SYSTEMS

A system to propel tiny satellites using electrical energy.

NATALYA BAILEY HELPED DEVELOP A way to propel satellites as small as a shoebox or as big as a refrigerator using engines about the size of a dime. It's based on so-called electrospray propulsion—the idea of using electrical energy to drive small rockets.

Electrospray technology has been in the works for many years. Researchers started studying it in the 1950s, but the work was abandoned because it required very high voltages and because the physics involved was not well understood. Bailey was able to use the technology's advantages—it's energy-efficient and doesn't require toxic propellants or pressurized tanks—to create tiny engines that can be used independently or in tandem with other engines, depending on the size of the satellite.

Bailey founded Accion Systems, just outside Boston, to commercialize the technology. She says the rocket-science field can feel like an old boys' club but she's made it work. "Being one of very few women in this field makes me stand out more," she says. "And I think it probably led to some opportunities that I maybe wouldn't have had otherwise."

—Erika Beras

Ashutosh Saxena

34 BRAIN OF THINGS

When his smart speakers didn't work as well as hoped, he built a better system.

Ashutosh Saxena is the CEO and cofounder of Brain of Things, which developed an AI system called Caspar that turns a home into a sort of robot that we can talk to and interact with. By later this summer, Caspar will have been installed in about 500 apartments in California and Tokyo.

Each of these apartments is outfitted with around 100 devices including motion and humidity sensors, microphones, cameras, thermostats, and automated appliances. All of these feed data about residents' behavior to Caspar, which uses a number of algorithms to analyze the data so that it gradually learns and adapts to people's habits and preferences.

If you tend to ask a lot of questions about the packages you are expecting, Caspar will learn to send you alerts when they arrive. It will also learn to tailor its music playlist to what you are doing at the moment.

When asked whether it's safe to entrust so many intimate details of our lives to a computer, Saxena says the sensitive raw data generated is stored within the home and not uploaded to the cloud.

The idea of creating Caspar came about in 2015, when Saxena and his roommate took home a couple of smart speakers. These devices, such as the Amazon Echo, can play music, order things online, switch the lights on and off, and do many other things around the house. But the roommates struggled to make the gadgets work the way they wanted them to. The virtual helpers sometimes turned off the wrong light, and when their masters' schedules changed, they couldn't adjust their control of other devices accordingly.

So Saxena, a robotics researcher, decided to build a better system.

"You no longer need to worry about packages not arriving at your home," Saxena says. "Caspar notifies you of such things, orders dishwasher soap, or controls your home environment according to your preferences." *—Yiting Sun*

Qi Yin

30 MEGVII

His face-recognition platform transformed the way business is done in China.

Seven years ago, Qi Yin founded a company called Megvii with two college friends in Beijing. Now people from over 220 countries and regions use Megvii's face-recognition platform, Face++. The company has more than 1,000 employees.

Face++ has transformed businesses in China, both online and offline. Airports and train stations use face recognition to expedite the screening process; banking apps use it to confirm the identities of their users.

Being in China has given Megvii an edge. While the use of face recognition in the West has mostly been confined to consumer-oriented applications such as unlocking smartphones, in China the same technology enjoyed strong backing from the government and big companies right away. This gives Megvii ample opportunities to commercialize its algorithms for industries as diverse as public security, real estate, finance, and retail.

Yin admits privacy is an issue. He says his products process sensitive raw data on local devices instead of uploading them to the cloud. He'd also like to see an industrywide standard on user privacy. "When there is a good system to manage and run these technologies, the benefits they will bring will outweigh the drawbacks," he says. *—Yiting Sun*

CHELSEA MUDLO (BAILEY); DAN LI (YIN); COURTESY PHOTO

Ji Xu

33 ALIPAY

His payment system lets anyone with an internet connection use financial services.

Ji Xu led a team that built the world's largest payment platform, which can support more than a billion transactions a day. It's a boon to commerce, but more important, it enables anyone – especially people without access to traditional banks – to use financial services over the internet.

Originally developed to make payments on Alibaba's online shopping sites easier and more reliable, Alipay has become a ubiquitous electronic payment app in Chinese e-commerce and brick-and-mortar stores alike. It has 520 million users, who see cash as a thing of the past: whether grocery shopping, paying utility bills, or buying movie tickets, they simply pull out a smartphone and use Alipay to scan a payment code.

As its business grew, Alipay was confronted with two challenges. First of all, it needed to increase the number of transactions it could handle. In addition, it needed to manage a growing variety of funding options. People had started linking all sorts of funds – credit cards, debit cards, electronic cash gifts, and investment portfolios – with Alipay to pay for things, and sometimes one purchase was made using multiple types of funds.

As the chief architect of Alipay's core payment platform, Xu led a team that increased the system's capacity from 10 million to 100 million transactions a day, and eventually to one billion. The new system can use servers located anywhere without causing delays during peak hours, which is crucial because the servers consume so much power that no single location can support enough of them to meet the system's requirements.

The increase in Alipay's transaction capacity also made it possible to offer online financial services to anyone, regardless of income level. One popular feature of the app lets users invest their leftover cash from online spending in a fund and earn interest at higher rates than they could at a bank.

Growing up near Hangzhou, where the Alipay team is based, Xu was not interested in taking exams. He spent about two years in a computer science program in college before leaving to look for a job, and he joined Alipay at 23. "I wanted to learn technologies," he recalls. While on the job, he caught up on programming knowledge through online courses.

—Yiting Sun

Xu led a team that increased the system's capacity from 10 million to 100 million transactions a day, and eventually to a billion.

William Woodford

32 FORM ENERGY

Finding the materials for the next generation of grid-scale batteries.

For renewables to work, they need batteries—otherwise, the lights go out when the sun goes down or the wind isn't blowing. Companies like Tesla and Hyundai are addressing the problem by developing football-field-size lithium-ion batteries in Australia and South Korea.

These massive batteries, however, are expensive.

"There's a cost floor to lithium-ion, which is dictated by the components that are used," says William Woodford, the chief technology officer of Form Energy. "No matter how cheaply you put it together, you still have a certain set of active ingredients, and those have costs." So while Elon Musk can build bigger, cheaper batteries, there's a limit to how cheap they'll ever get. Lithium carbonate, for example, can cost as much as $20,000 a ton.

To address this problem, Woodford has identified metal-sulfur chemistries that could beat lithium-ion technologies for long-term storage and cost. As a bonus, sulfur is cheap and abundant: it often goes unused as a waste product of oil and gas production. *—Dan Solomon*

IRIS WANG (XU); DINA YURYEV (WOODFORD)

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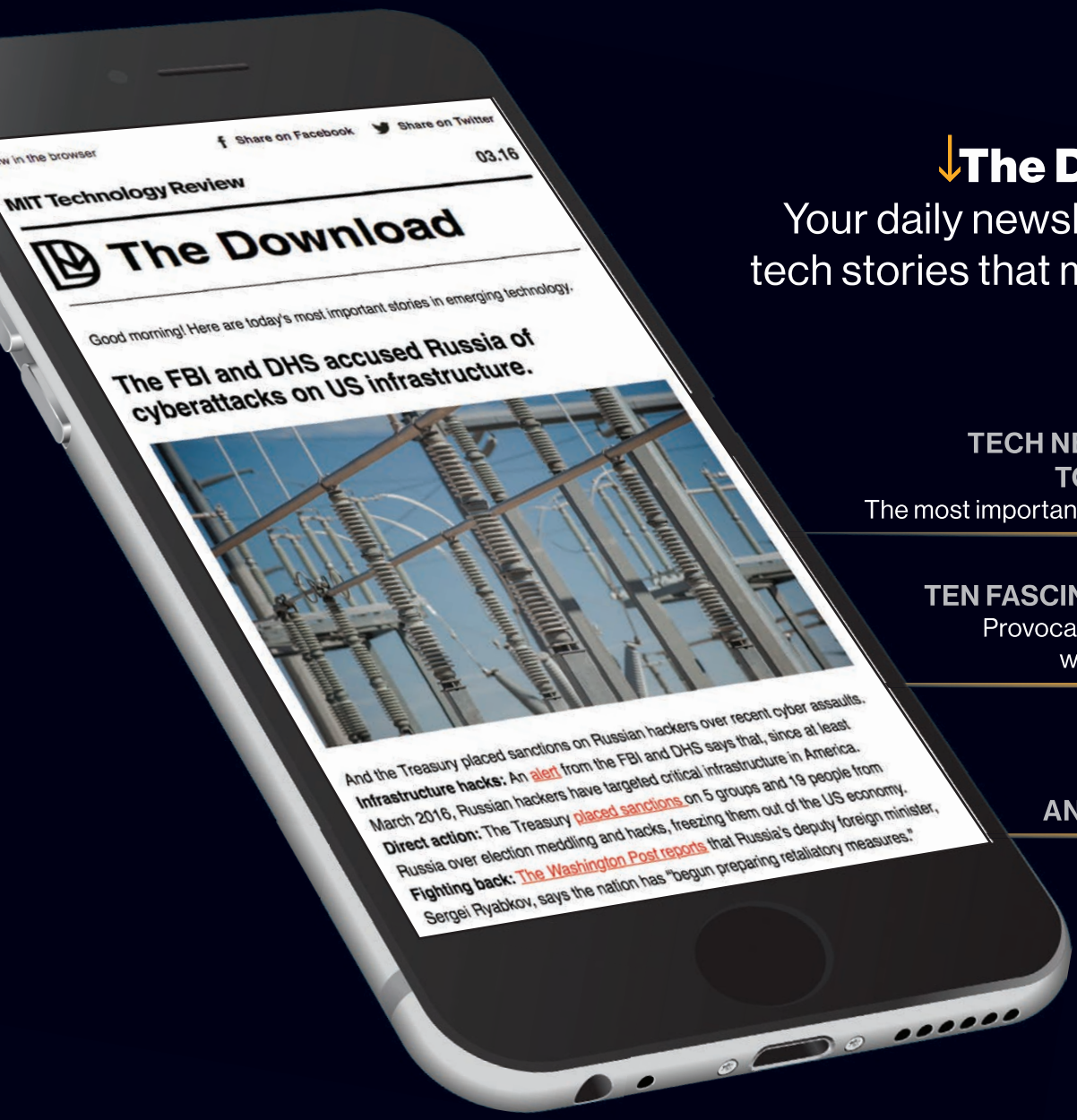

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